QATAR UNIVERSITY

COLLEGE OF ENGINEERING

ECONOMETRIC AND ENVIRONMENTAL ANALYSIS OF RESIDENTIAL SOLAR PHOTOVOLTAIC SYSTEMS IN QATAR

BY

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ABSTRACT

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Title: Econometric and Environmental Analysis of Residential Solar Photovoltaic Systems in Qatar

Supervisor of Project: Mohsin Kh. Siddiqui.

Qatar's economy has grown drastically over the last decades. Extreme industrial expansion and economic growth, alongside the rapidly increasing population and rising living standards put continuously increasing pressures on domestic energy consumption leading to the soaring demand for electricity.

The direct relation between domestic energy demand and the most important export products - oil and gas - has posed an interesting policy challenge. Seeking power generation from renewable solar energy resources to replace the use of conventional oil and gas resources has become feasible due to the increasing concerns of depleting oil and gas resources and environmental concerns.

This research project discusses the opportunity and advantages of utilizing the renewable solar energy in power generation in the State of Qatar. The research aims to provide an economic and environmental analysis assessing the effectiveness of solar energy technologies (more specifically the solar Photovoltaic (PV) panels in residential buildings) in Qatar. Economically, the cost of utilizing the Photovoltaic module is assessed by calculating the system equivalent annual savings and economical net present

value (NPV), taking into consideration the initial installation cost in addition to the annual operation and maintenance cost. Moreover, a sensitivity analysis using Monte Carlo simulation is presented for different discount and tariff rates as well as different system installation and Operations & Maintenance costs. Environmentally, the corresponding reduction in the CO_2 emissions at the base station and its equivalent estimated cost saving is calculated and the NPV is recalculated considering the CO_2 savings amount.

This project proposes energy policy for Qatar supporting the utilization of solar Photovoltaic system in residential buildings, and estimating a suitable subsidy level to minimize the total system annual cost to the customers making it economically attractive.

DEDICATION

Dedicated with love and gratitude

To the memories of my dearest Father Shabib M. Haimour (1958-2011).

"They may not know how much you meant to me."

To my one and only Mother Suhaila Z. Taweel, who encouraged me to go on this adventure. For her advice, her patience, and her faith.

Because she always understood.

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my supervisor Dr. Mohsin Kh. Siddiqui for his support and mentorship throughout this project.

I would like to extend my thanks to the college of engineering faculty and staff and those who offered guidance and support throughout the years.

A special thank you to my family, my friends, and my sister Eng. Tamara Sh. Haimour without whom this work would never be completed.

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CHAPTER 1. INTRODUCTION AND BACKGROUND

Section 1.1 Background

Qatar is a small country yet ranking worldwide among the highest per capita in: income, production and proven reserves of oil and Natural Gas (NG), energy and water consumptions, CO2 emission, and water food production shortage. (Darwish, 2013)

Qatar is a significant producer of energy, its energy production in relation to the population size is remarkable. It is one of the largest natural gas producers globally, the home of world’s third largest natural gas reservoir covering more than 14 % of the global known natural gas reservoirs. Moreover, it was the 11th largest oil producer in OPEC in 2008, making it one of the most substantial oil suppliers regionally and globally. Being one of the world’s key centers of oil and gas supply, has turned Qatar in the last few decades into the wealthiest country worldwide, ranked number one on the list of top ten richest nations for its phenomenal high GDP per capita. (Natural Gas in Qatar, 2016)

However, In the last decades fossil fuels have been extensively utilized in power generation, due to the world's rapid development and growing power demand in addition to the over dependency on oil and gas as the main energy source in the process of generating electricity. This over utilization has intensively amplified the global concerns of draining limited fossil fuels resources as well as global worming alarms .As a result, the world started exploring new alternating energy resources in order to mitigate the risk of energy crisis and limit the environmental damages due to the burning of fossil fuels.

One of the most pursued options for renewable energy sources is solar energy. This endless source of energy is highly preferred by countries having average of 3-6 kWh/m^2 daily solar radiation levels in achieving their target of clean and sustainable power generation, due to its indefinitely productivity, natural friendly, and sited-dependency nature (Elhadidy & Shaahid, 2008).

Solar energy economics are improving as it becomes more cost competitive than in mid-2000's when it was an innovative technology receiving the attention of all investors and generous subsidies. The potential of solar energy industry still stand out, despite of the multiple factors that challenged its short-term performance between 2011 and 2013; such as the financial crisis, cheap natural gas, imports from Chinese solar manufacturers, and bankruptcy of many solar companies. The average global installations of solar systems has increased since 2006 by more than 50 percent, increasing the role of solar industry and occupying a larger portion in the global energy markets. This potential and continuous development directly impacts the utility sector consumers and business (Frankel, Ostrowski, & Pinner, 2014).

One of the main reasons behind the increasing potential of solar power is the reduction in solar systems prices. For instance, a rooftop best quality US PV system installation price reduced from $7 per Watt in 2008 to less than $4 per Watt in 2013 as a result of decreasing in installation costs and module material costs (Frankel, Ostrowski, & Pinner, 2014).

Solar Photovoltaic is one of the solar energy electric converting devices that use semiconductor materials to directly convert solar energy into DC electricity, and known globally as PVs. To collect the largest possible amount of solar energy, hence sunlight, large areas of the semiconductor is needed. For this reason the semiconductor cells are deposited in a continuous very thin layers on a supporting materials, electrically wired and sealed into a waterproof module. The PV modules, combined with a set of additional application-dependent system components (e.g. inverters, batteries, electrical components, and mounting systems), form a PV system. PV systems are highly modular; i.e. modules can be linked together to provide power ranging from a few watts to hundreds of megawatts. Modern PV modules usually have between 48 and 72 cells and produce from 25 to 40 volts of dc with average power output of 150 to 300 Wp (Grid-connected solar systems, 2016)

Section 1.2 Utility Sector Structure

Up to 1999, electrical power generation, transmission, and distribution were all carried out by the Ministry of Electricity and Water (MEW). However, privatization of power generation services has taken place in 2000 by establishing Qatar Electricity and Water Company (QEWC) to encourage private investors, increase the utility generation capacity, and to enhance deregulation. Since that time, power generation and production were performed by different public and private sectors following a split-sector model of electricity and water sector. (KAHRAMAA Statistics Report, 2014)

Therefore, the established additional utility generation facilities were concerned to expand the capacity and to meet the increasing power demand in the country. Hence, Qatar General Electricity and Water Corporation (KAHRAMAA) was responsible of the government services including: electricity transmission and distribution, and water forwarding and distribution. (KAHRAMAA Statistics Report, 2014)

KARAMAA now operates and maintains the major electricity and water network in Qatar by delivering these basic services to all consumers. On the other hand, expanding the deregulation in this sector by collaborating with the government to encourage the entrepreneur citizens to invest in the power generation and water desalination business, also known as IPWP's (Independent Power and Water Providers). (KAHRAMAA Statistics Report, 2014)

The basic source of natural gas fuel for the Power and Water Production facilities run by the IPWP's is QP (Qatar Petroleum). The linkage of four major organizations in Qatar that constitute in the supply chain to the costumer is shown in the following diagram:

Figure 1. High level diagram for the Electricity and Water Supply Chain in Qatar. Source: **(KAHRAMAA Statistics Report, 2014)**

As shown in the previous diagram, KARAMAA is the connecting link between the IPWP's and the customers; where it is responsible of estimating the electricity and water demand in the country, further, negotiating and initiating with IPWP developers for the construction of new desalination plants and power stations. QP plays a vital role in this chain by providing the natural gas and oil required for the IPWP developers. (KAHRAMAA Statistics Report, 2014)

As KAHRAMAA is an intermediate entity between the IPWP's and the consumers, it purchases all generated electricity and desalinated water by the IPWP's, which is then sells on to customers based on determined rates. In addition to the revenues from the sale of electricity and water, KARAMAA receives some funding from the state. Hence, KARAMHAA operates on commercial principles.

KAHRAMAA is also responsible for capital investment projects in the sector, by establishing public-private partnerships (PPPs) starting back from 2001, after KAHRAMAA's foundation. Examples of these partnerships: Ras Laffan A water and power project, Ras Laffan B, Measaieed A, and Ras Laffan C. The total generation capacity of power projects is 6500 MW. Another example of these partnerships is building a desalination components project, such as the current project under way, Facility D; a 2520 MW gas-fired power plant with an associated desalination plant. (The Report: Qatar 2016, 2016)

By the end of 2014, the National Campaign for the Conservation and Efficient Use of Water and Electricity in Qatar (Tarsheed) was formed under KAHRAMAA. Tarsheed is concerned with aligning KAHRAMAA's policies with environmental sustainability in a way that satisfies Qatar National Vision 2030. Overall, KAHRAMAA follows the environmental regulations set by The Ministry of Municipality and Environment, including: the accepted level of emissions from power and water plants, and the accepted amounts of the discharge of brine (the liquid left over after desalinating sea water) back into the Gulf waters. (The Report: Qatar 2016, 2016)

Section 1.3 Objectives and Scope

The main objective of this project to study the possibility of utilizing solar energy in Qatar for generating power for the residential sector. In attempt to reduce the dependency on domestic natural gas in meeting the growing power demand enabling additional exports, and reducing CO_2 emission . Moreover, this project aims to present a new energy policy for Qatar to support the use of renewable solar energy for the residential sector.

This will be achieved by assessing the economic and environmental effectiveness of residential PV system in Qatar. The economic analysis performed from the customer point of view, calculating the Net Present Value of a 1kW system after reviewing the system's installation and maintenance costs. The environmental analysis conducted by calculating the total amount and financial value CO_2 emissions saved by the system. Based on the results, an economically attractive electricity subsidy will be calculated as part of the proposed energy policy. The scope also includes evaluating the attractiveness of the studied system and the proposed subsidy using Monte Carlo simulation.

The scope of this project focuses on the residential PV systems sized between 1kW to 10kW.The technical performance simulations, system performance and cost optimization, and assessing different PV system alternatives will be out of the scope of this project. Also its worth to mention that the fossil fuels consumption rates and costs at the power plant and their related economic analysis is beyond the project scope.

CHAPTER 2. RESEARCH METHODOLOGY

The research methodology followed in conducting this study is summarized in the following list:

1. Study the power supply demand behavior in Qatar and the difference between the summer and winter peak demand.
2. Review the existing power generation plants load distribution and capacity in addition to the power distribution by sector in Qatar.
3. Study the energy consumption growth including the Natural Gas current and future prices as well as its domestic current and forecasted demand.
4. Examine Qatar's environmental situation in terms of the ecological footprint and CO_2 emissions.
5. Review the Solar PV cells prices and their market position.
6. Review the current electricity tariffs in Qatar
7. Review the financial value and amount of CO_2 emissions generated by the conventional power generation systems.
8. Review the installation and maintenance cost of residential PV system in Qatar and calculating the economics of the system installation for the customers.
9. Analyze the economical behavior of the system by introducing a varying subsidy level for a range of system costs and tariff rates.
10. Conduct sensitivity analysis using Monte Carlo simulation evaluating the attractiveness of the system and the introduced subsidy; by varying the system

installation cost, operations and maintenance annual cost, in addition to the electricity tariff and discount rates.

11. Review the solar energy potential in Qatar and the common supporting policies in the region and worldwide.
12. Formulate a supporting policy for the residential PV system implementation including the condition of the supported systems and consumers.
13. Evaluate the environmental benefits of the residential PV system and the corresponding CO_2 savings financially.
14. Calculate the system economic value considering the environmental financial savings and compare it with the economic value without the environmental financial savings.

CHAPTER 3. EXISTING POWER CHALLENGES

Section 3.1 Continuous Increasing Power Demand and Supply

Qatar, like many of its GCC neighbors, has long been a large consumer of power. Qatar has the third-highest electricity consumption rate in the Middle East, in per capita terms. (Natural Gas in Qatar, 2016)

Over the past fifty years power consumption in Qatar has grown significantly. The maximum network load between 1988 and 2003 increased from 941MW to 2,312MW reaching 3,230 MW in 2006. Between 2001 and 2011 power demand increased by a compound annual growth rate (CAGR) of 9.3% due to the population expansion and significant GDP growth rates. The number of electricity customers increased from 2010 and 2014 with an average annual growth rate of 5.8%. However, the number of customers raised by significant 7.8% growth rate from 2009 to 2010 and 2010 to 2011.The growth of customers' rate between 2011 and 2012 was the lowest, only 1.6% .The growth between 2013 and 2014 was 5.6%. The number of customers was 252,893 in 2010, increasing in the subsequent years reaching 310,107 customer in 2014, according to a report published by Qatar General Electricity and Water Corporation (Kahramaa). (KAHRAMAA Statistics Report, 2014)

Consequently, Kahramaa's power generation was pumped from 28,144 GWh in 2010 to 38,693 GWh in 2014, by an average annual growth rate of around 10%. Although the number of consumers was increasing, a slight decrease in electricity generation from 34,788 GWh in 2012 to 34,668 GWh in 2013 was recorded, there was marginal fall at rate of 0.3% in 2013 compared to the previous year 2012 meeting the dropped demand from 6,255 MW to 6,000 MW. The significant expansion continued in 2014 reaching production of 38,693 GWh. The highest growth during the four-year period was 13.2% in 2012, compared to 2011.Also there was an impressive increase in 2010 by 16.5% compared to the previous year of 2009.

The peak power demand has increased between 2010 and 2014 from 5,090 MW to 6,740 MW at an annual growth rate of 8.5%. However ,the highest growth rate was recorded at 16.4% in 2012 ,followed by a significand dropp recording the lowest rate of 4.1% reduction .The demand then raised again in the next year of 2014 by 12.3% hitting the highest demand of 6,740 MW over the five years period. The below figure illustrates the electricity generation behavior from year 2010 to 2014. (KAHRAMAA Statistics Report, 2014)

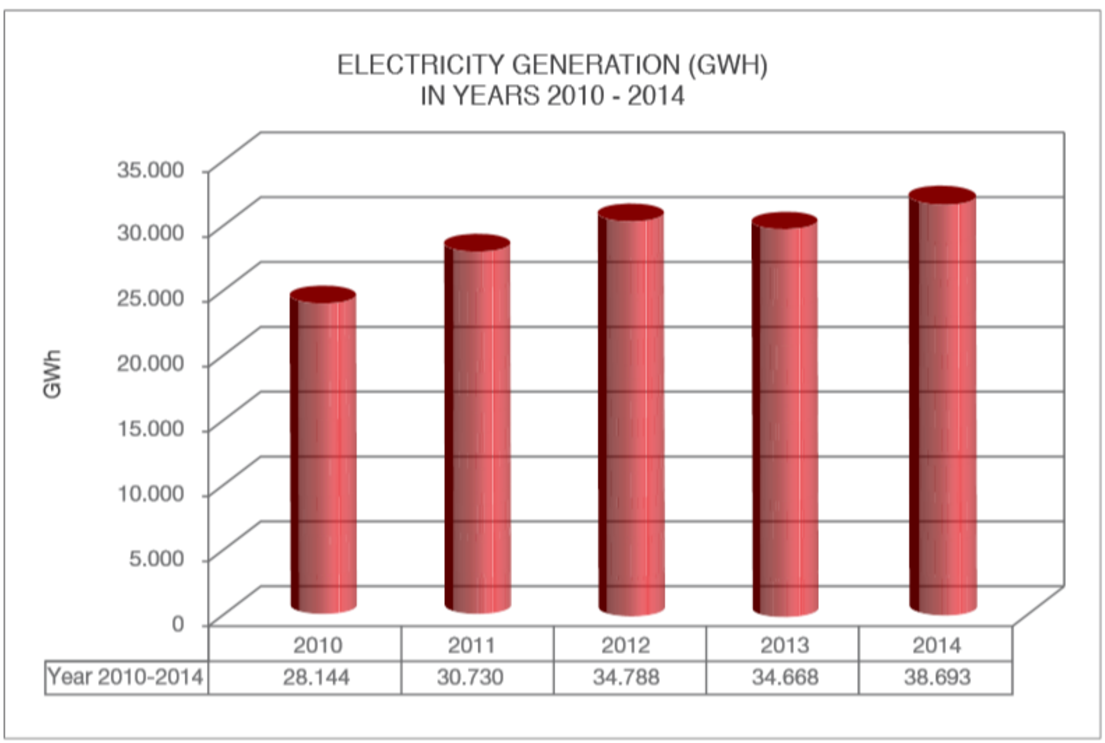

Figure 2.Electricity Generation behavior (GWh) from 2010 to 2014

The above mentioned figures continue increasing, as the existing production capacity for 2016 is 8,600 MW with a peak electricity demand of 8,200MW .Moreover, by the end of 2018 the power generation capacity is expected to reach 13,000 MW as part of the Utility expansion projects and the country's readiness for the 2022 FIFA World Cup (al-Mohannadi, 2016).

Section 3.2 Power Generation Plants Load Distribution and Capacity

In attempt of meeting the growing power demand, Qatar has expanded its production capacity by building more power generation plants. The following figure published by Kahramaa shows the existing power plants in Qatar in 2014 alongside their capacity in MW. Ras Laffan C (Ras Girtas Power Company) has the largest plant capacity of 2,730 MW followed by Mesaieed PowerStation with 2,730 MW capacity, while Ras Abu Fantas Satellites has the lowest capacity of 183 MW. The total capacity of all the plants approximately reaches 8.791 MW. (KAHRAMAA Statistics Report, 2014)

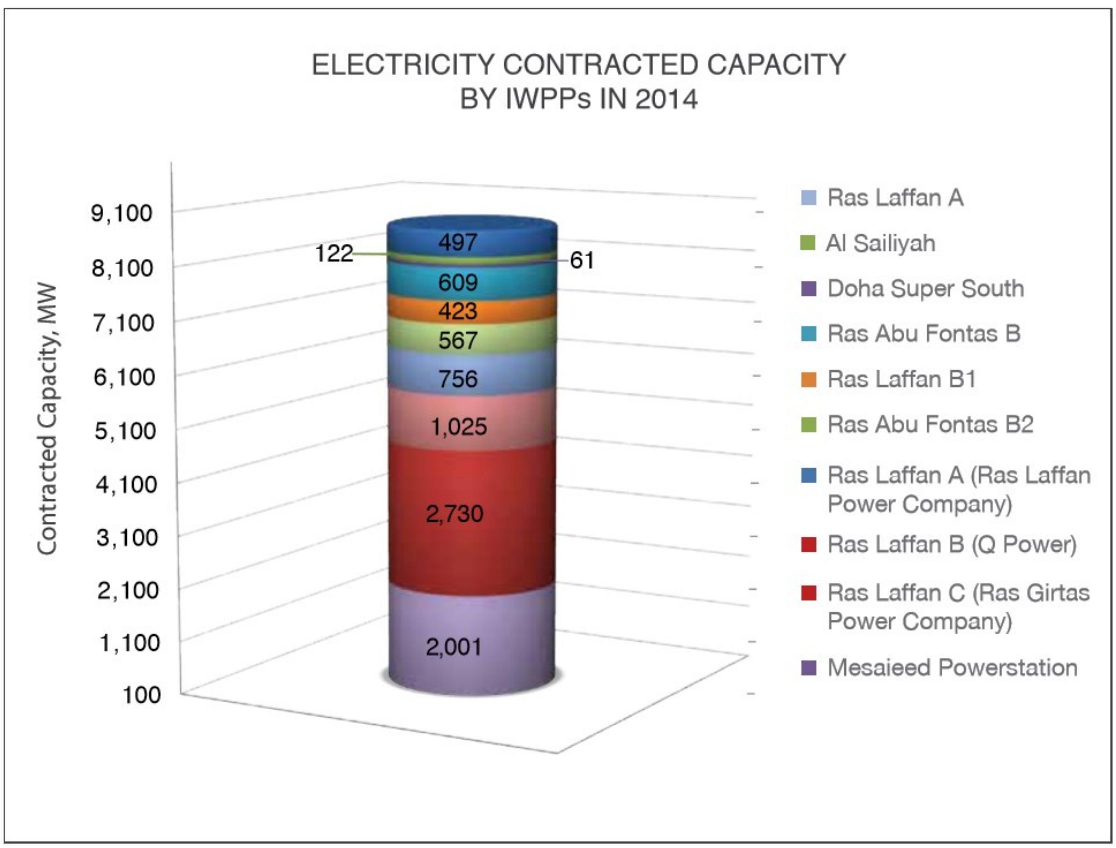

Figure 3. Electricity Contracted Capacity by IWPPs in 2014. Figure source: **(KAHRAMAA Statistics Report, 2014)**

Section 3.3 Energy Consumption and Projected Growth in Fossil Fuels Usage

Power plants in Qatar completely depend on natural gas as the only source of energy. The country uses zero coal. Power plants use Combined Cycle Gas Turbines (CCGT) in the process of electricity generation. CCGT are a form of highly efficient energy generation technology that combines a gas-fired turbine with a steam turbine, and it is typically powered using natural gas. Hence, the country doesn't have major alternating energy projects under execution (Combined Cycle Gas Turbine (CCGT), 2010). The next figure illustrates the installed power generation capacity by type for the GCC in 2012. Qatar's power generation is intrinsically linked to its natural gas resources.

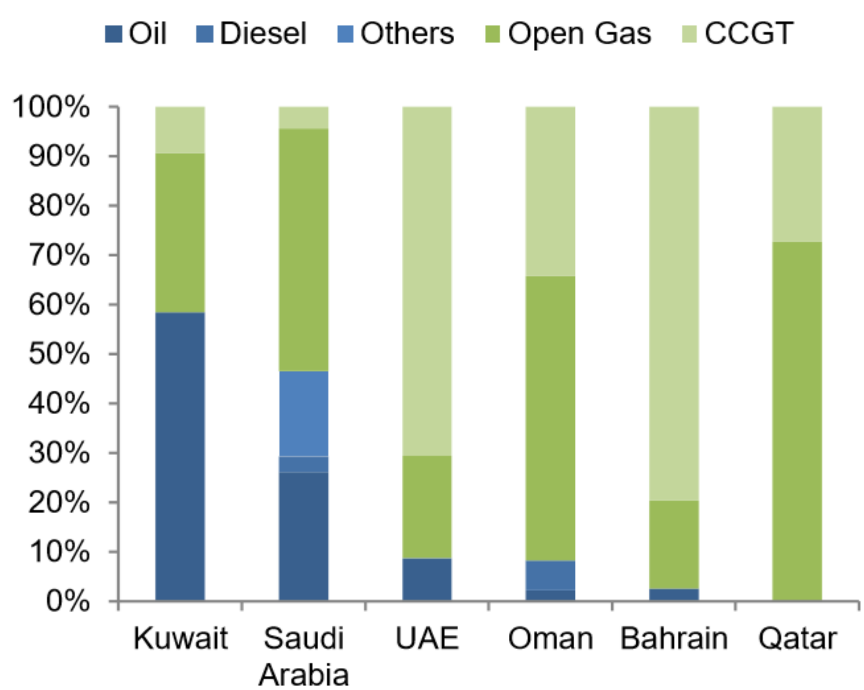

Figure 4. Installed power generation capacity by type for the GCC in 2012. Source: **(El-Katiri & Husain, 2014)**

The next figure shows the annual natural gas consumption in each of the existing power generation plants for 2014 in Qatar. As shown in the figure, RAF B1 consumes the lowest amount of 28,742,276 MMBTU annually in generating 2,477,067 MWh

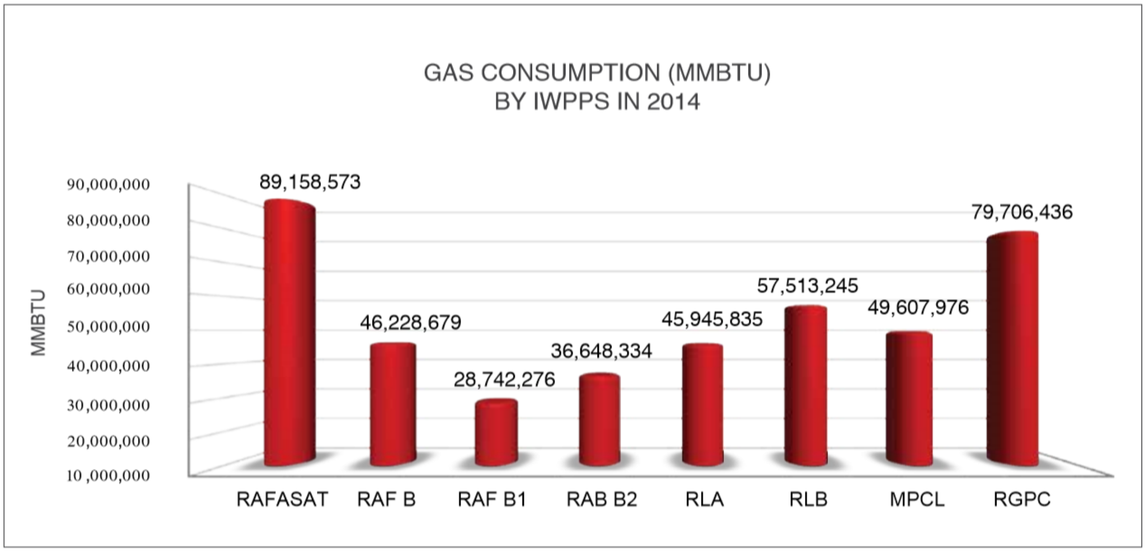

Figure 5. Annual Gas Consumption (MMBTU) By Power Generation Plants in Qatar in 2014. Figure source: **(KAHRAMAA Statistics Report, 2014)**

According to the latest Kahramaa's statistics report, the total gas consumption in power generation is 433,551,354 (MMBTU). The next figure shows the total monthly gas consumption based on 2014 total power plants' consumption data. The figure illustrates the trend of gas consumption throughout the year, starting from January with total of 26,589,176 MMBTU dropping in February to almost 24,348,397 MBTU and recording its minimum level. However, the figure shows a significant jump in the summer period between June and September reaching peak level of 45,276,561 MMBTU in August. (KAHRAMAA Statistics Report, 2014)

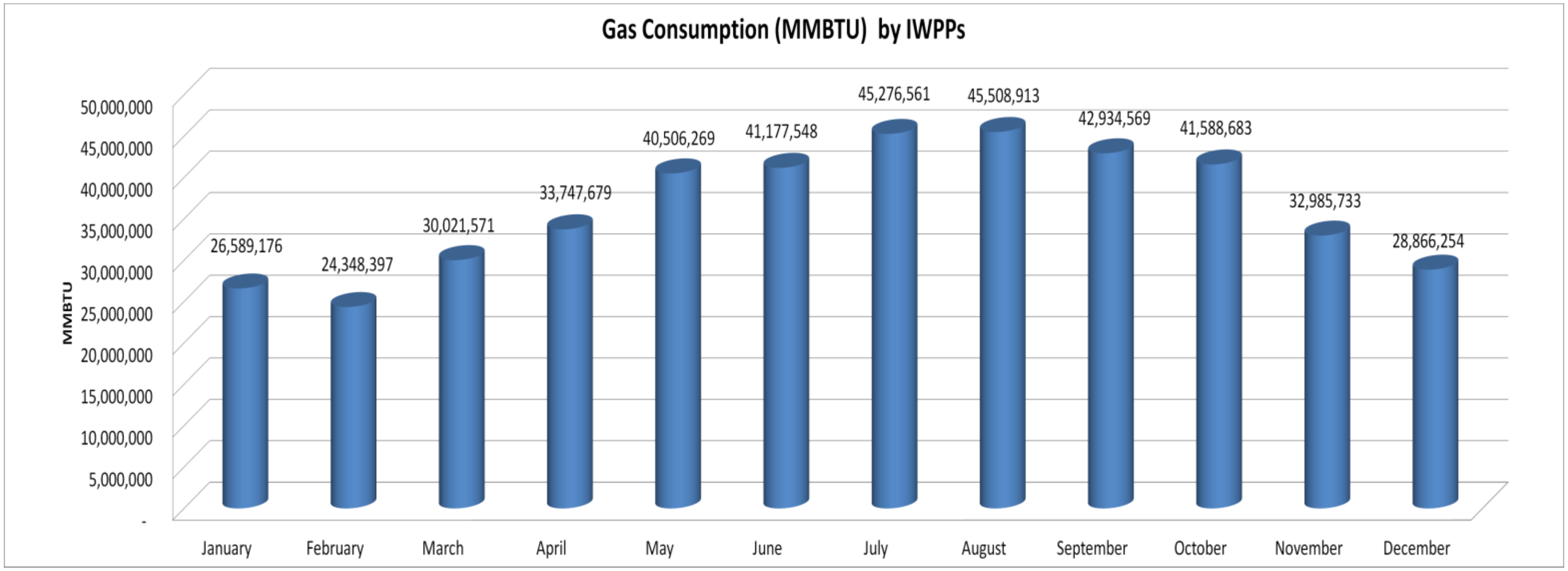

Figure 6. Total monthly gas consumption based on 2014 total power plants' consumption data. (Data table in appendix)

In light of this, the natural gas domestic consumption by utility plants in Qatar nearly tripled in the decade to 2013.This movement strongly associated the production growth that quadrupled in the same period, according to the US Energy Information Administration (EIA) as highlighted by (The Report: Qatar 2016, 2016). Natural gas consumption in Qatar stood at 24.9bn cu meters in 2009, and increased to nearly 44.8bn cu meters in 2014, according to BP "Statistical Review of World Energy" 2015 report (The Report: Qatar 2016, 2016). Hence, a significant increase in the figures is expected for the upcoming year's production due to the increasing power production capacity and demand mentioned in section1.

Natural gas historical data

Natural gas prices are influenced by several factors, for instance: oil prices and world's demand. Natural gas demand worldwide is continuously increasing due to the noticeable natural gas prices decline from the end of 2008 as shown in next figure based on (Henry Hub Natural Gas Spot Price, 2016)

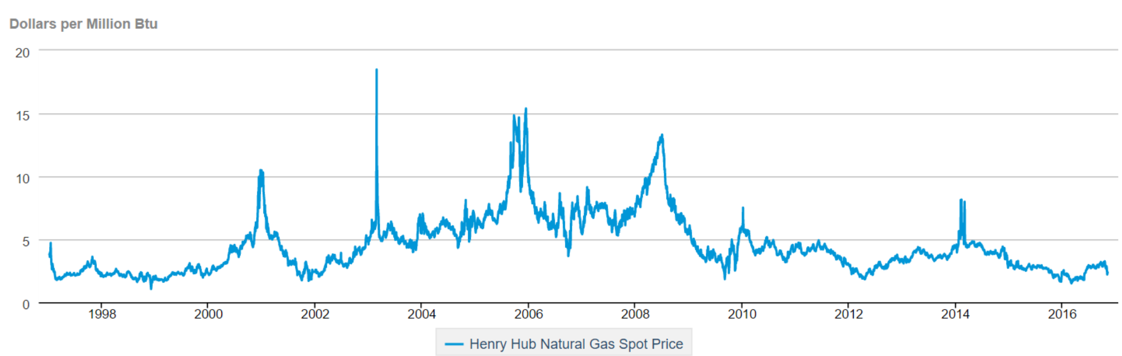

Figure 7. Trend of natural gas prices between 1997 and 2016

Natural gas current and future prices

Natural gas international current prices are approximately 2.26$/MMBTU, while local prices in Qatar are normally cheaper than international prices. Natural gas local price is 1.58$/MMBTU based on values estimated in 2015.

The future price of natural gas is expected to increase to a value of approximately 3.9$/MMBTU in 2020 as shown in next figure (Natural Gas Prices: Long Term Forecast to 2020 | Data and Charts, 2016)

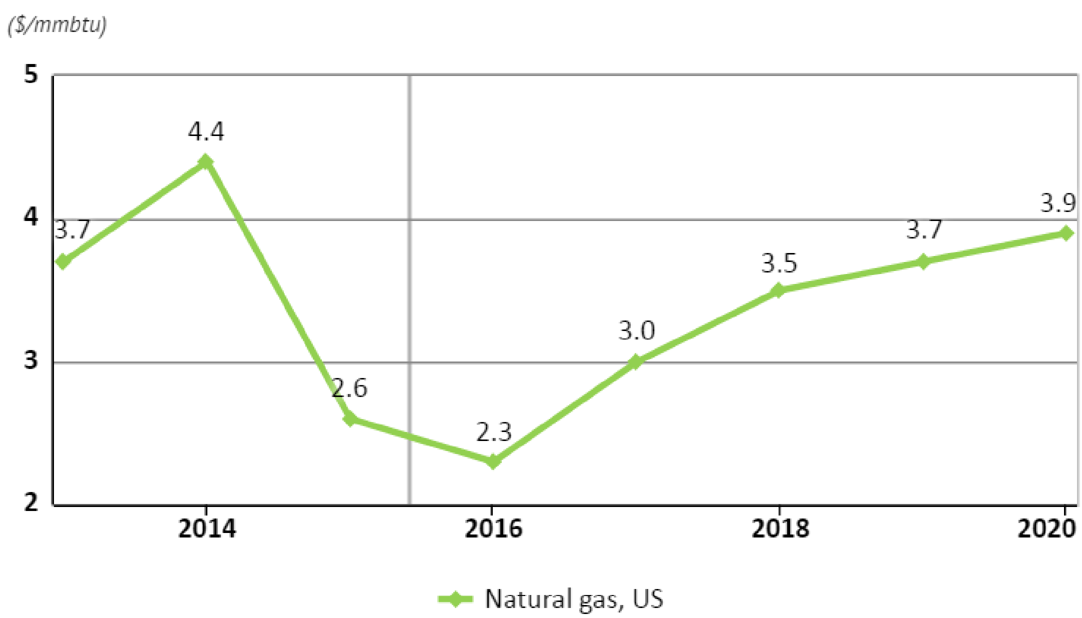

Figure 8. Natural Gas Price Forecast. Source: (Natural Gas Prices: Long Term Forecast to 2020 | Data and Charts, 2016)

Domestic Demand Future Forecast

The following figure shows the current and projected growth in the gross domestic energy consumption for the GCC, mtoe. (El-Katiri & Husain, 2014)

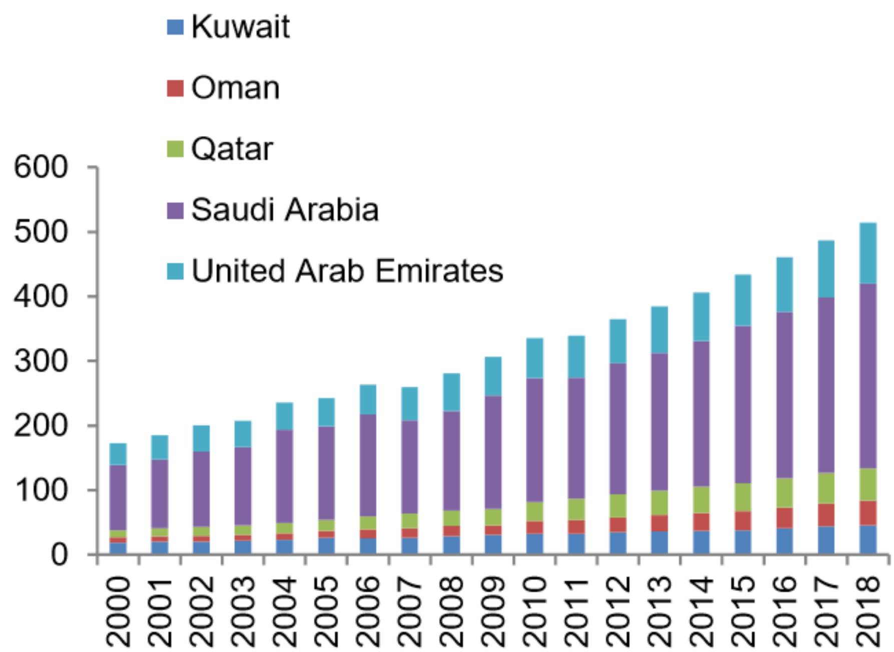

Figure 9. Current and projected growth in the gross domestic energy consumption for the GCC, mtoe.

Figure source :(El-Katiri & Husain, 2014)

According to the above figure and as highlighted by (El-Katiri & Husain, 2014), the domestic energy demand is expected to continue rising at rates which are among the fastest over at least the next decades. Due to the low costs of oil and natural gas in the GCC states and Qatar as part of the GCC , in addition to the direct relationship between the energy generation, economic development ,and domestic energy consumption.

Most of the GCC states depend in their governmental revenues for up to 90% on their exports of oil and natural gas resources. In 2013, 85% of Qatar's exports earnings and 70% of government revenues were accounted by oil and gas, which placed Qatar as the highest income per capita country. (Darwish, 2013)

According to the Oil Price report , Qatar is in second place globally in terms of energy consumed per person after Iceland (Topf, 2014).

Where each citizen in Qatar consumes an energy equivalent to an average amount of 17,418kg of oil – based on the amount of energy that can be extracted from one kilogram of crude oil according to the World Bank figures. Thus, the increasing domestic oil and gas demand with the current demand and supply policy will put Qatar and other GCC states in a massive fiscal and macroeconomic problems in future (El-Katiri & Husain, 2014).

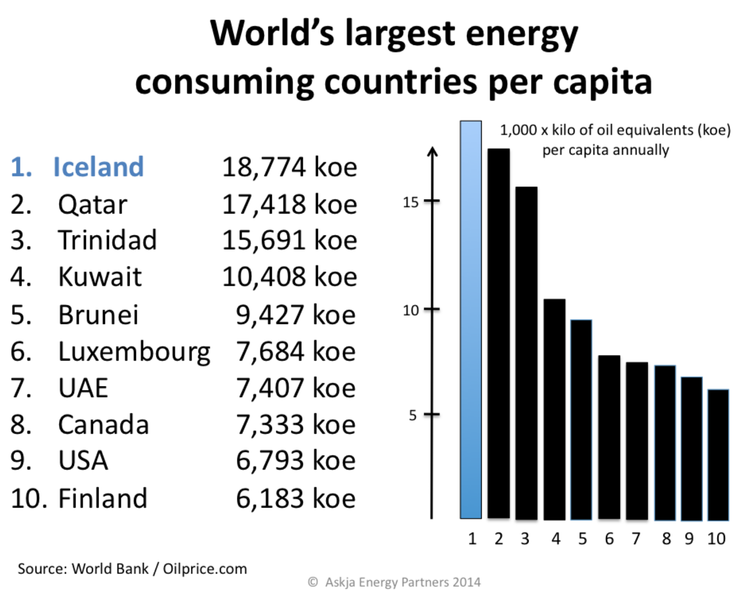

Figure 10. World's largest energy consumption countries per capita. (Source: World Bank)

Section 3.4 Power Distribution in Qatar

As shown in the figure below, the majority of power is consumed by domestic sector. Where 57% of total generated power in 2014 went to domestic sector, 30% to industry, 7% to auxiliary consumers, and 6% went as transmission losses.

According to the last available statistics report published by Kahramaa in 2014, the domestic consumption includes residential, commercial, and government. Auxiliary includes the power used by power plants in electricity generation and water desalination facilities. The maximum consumption was around 22,215,842 MWh for domestic followed by 11,568,215 MWh for industrial, 2,567,926 MWh for Auxiliary and the lowest portion of 2,340,897 MWh sent as transmission losses. The available Kahramaa reports don't show the detailed percentage distribution of domestic consumption although it wraps more than half of the state's electrical consumption.

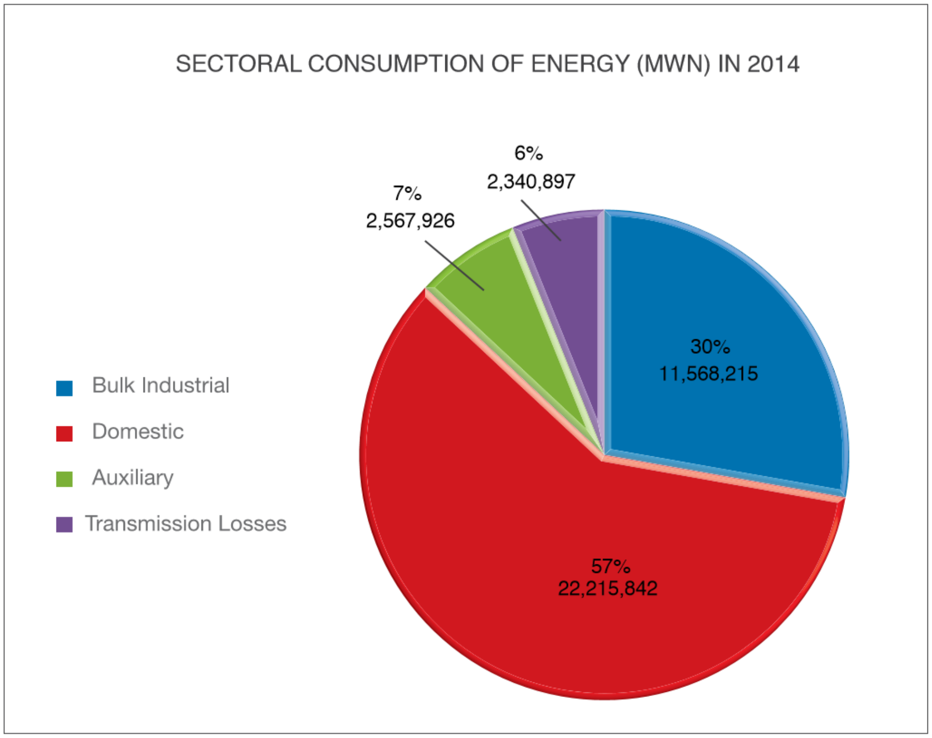

Figure 11. Consumption of Energy in Qatar in 2014, per sector .Figure source: **(KAHRAMAA Statistics Report, 2014)**

Domestic sector recorded the highest peak demand level over the five years period between 2010 and 2014.The domestic demand annual growth rate between 2013 and 2014 was 8% and the consumption growth rate was 10.4%.The domestic demand reached its maximum of 5,180 MW in 4 September 2014.On the other hand, Industrial demand recorded its peak in 2012 with 1,772 MW decreasing in 2014 to 1,317 MW then raising again with an interesting annual growth rate of 25.1% and consumption growth rate of 16.3%.The next figure provided by Kahramaa, records the peak demand by sector in the period between 2010 and 2014. (KAHRAMAA Statistics Report, 2014)

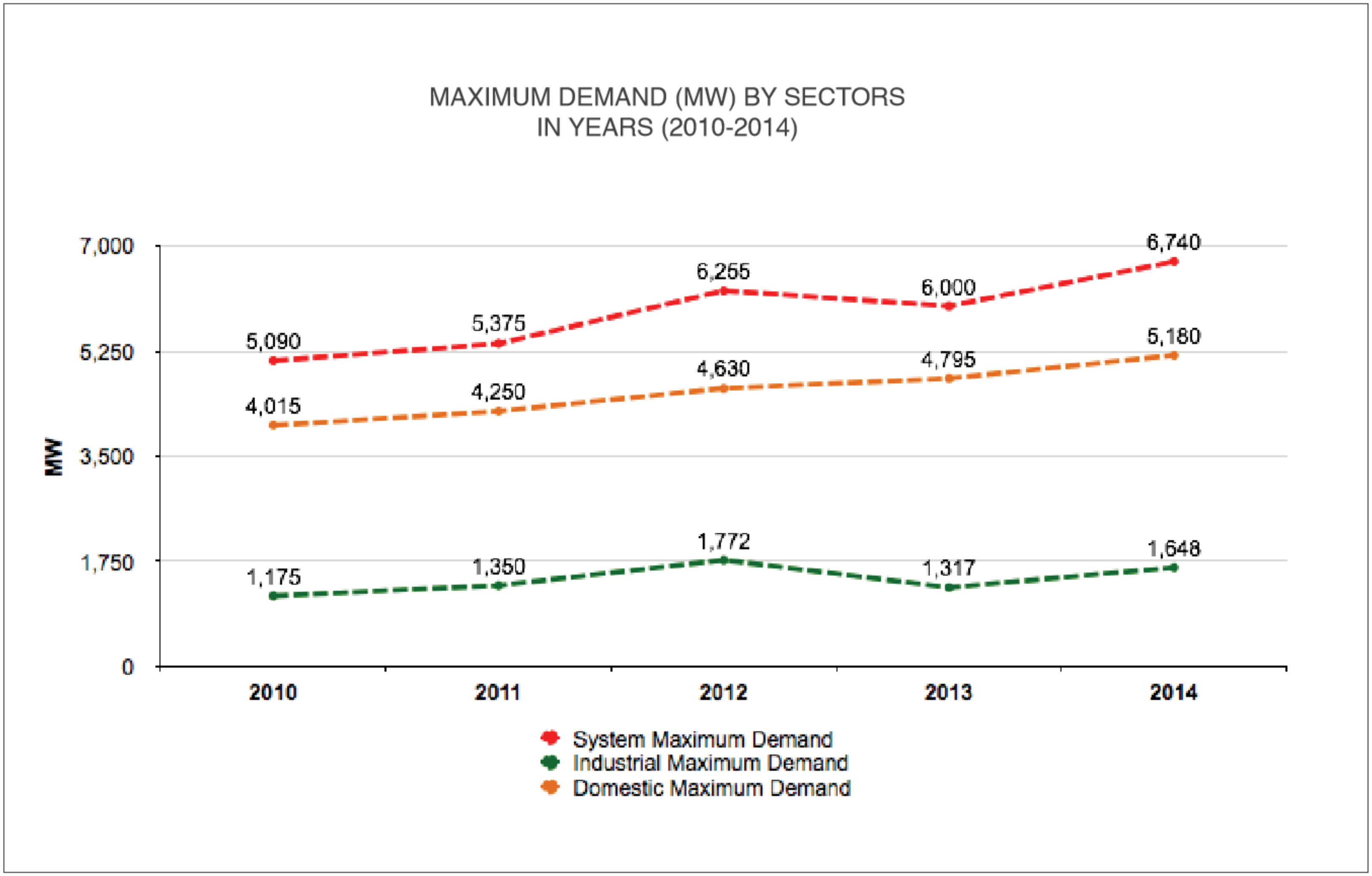

Figure 12. PeakdDemand by sector in the period between 2010 and 2014. Figure source :(KAHRAMAA Statistics Report, 2014)

Section 3.5 Difference Between Summer and Winter Peak Demand

The maximum and minimum peak demand from 2010 to 2014 alongside the date of each record are listed in the table below as published by Kahramaa. As listed, the maximum peak demand was reached in 7 September 2014 while the minimum peak of the same year occurred in nearly mid-February. The table shows that maximum peaks were reached in the summer period between July and September, while the minimum peak demands were recorded in the winter months January and February. This is associated with temperature levels in summer and winter which drives the energy air conditioners activity in commercial and residential buildings that increases obviously in the hot summer season.

Table 1. Maximum and minimum electricity load from 2010 to 2014, MW. Data source: **(KAHRAMAA Statistics Report, 2014)**

Year	Max. Load (MW)	Date	Min. Load (MW)	Date
2010	5,090	14-Jul	1,570	8-Feb
2011	5,375	1-Aug	1,785	13-Jan
2012	6,255	6-Aug	1,840	26-Jan
2013	6,000	18-Jul	2,046	16-Jan
2014	6,740	7-Sep	2,155	12-Feb

The extreme seasonal demand fluctuation is clearly exhibited in above table. The demand keeps swinging between summer and winter with a difference of more than 60%. In 2014, the difference between the maximum and minimum peak is nearly 4,585 MW in which the minimum winter peak is less than 68% of the maximum summer peak. The next figure presents the half hourly load curve for maximum and minimum demand in2014, clearly showing the maximum summer demand in September 7th,2014 at 15:00 when the temperature was in its highest in addition to other factors beyond the scope of this report.

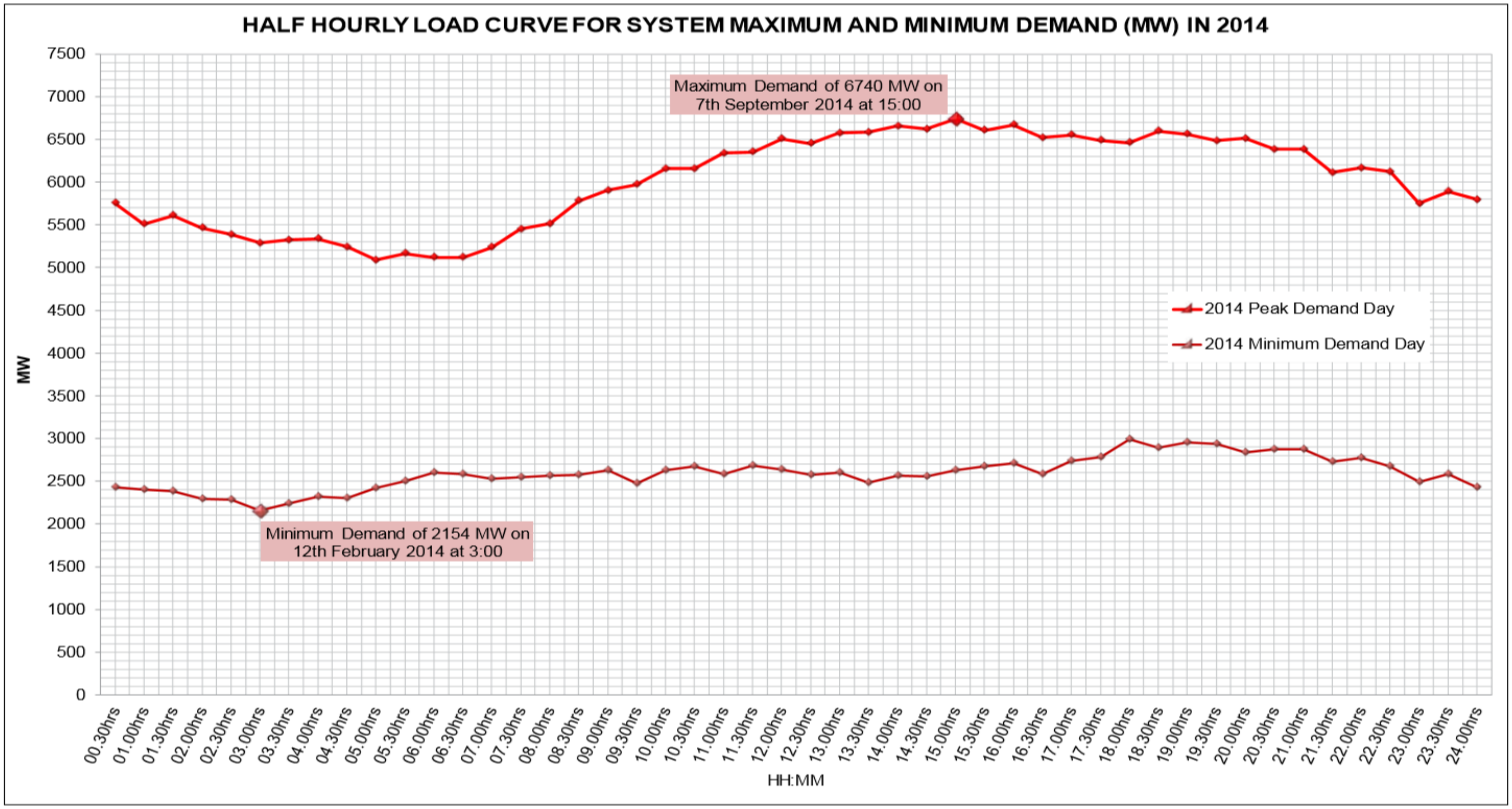

Figure 13. Half hourly load curves for system maximum and minimum demand (MW) in 2014. Figure source: **(KAHRAMAA Statistics Report, 2014)**

Due to the above, maintaining a reserve margin of 30% during peak loads was managed by Kahramaa , by investing heavily in expanding and operating the power generation plants. Moreover, the above peak demands don't last for long period, the reason that causes enormous losses due to operating and maintaining the plants for large generation capacities. The next figure depicts the Electricity Supply and Demand Balance chart in 2013. (KAHRAMAA Annual Performance Report , 2013)

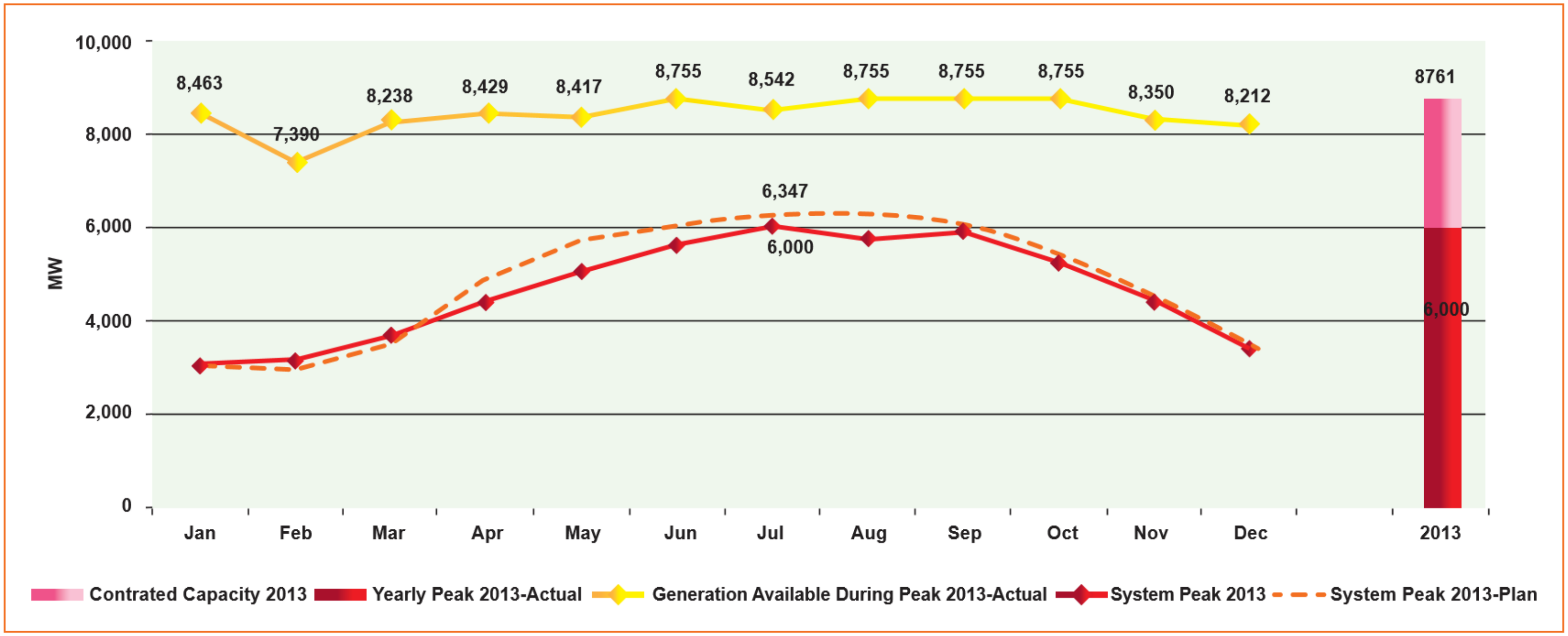

Figure 14.Supply and Demand balance of electricity. Figure source: **(KAHRAMAA Annual Performance Report , 2013)**

Section 3.6 Environmental Situation

Ecological Footprint

Over the past few years, GCC environmental record has been improving. However, still ranked by the World Wide Fund report amongst the top consuming countries for productive land and water. According to (Living Planet Report 2014, 2014), GCC countries were ranked as the second highest ecological footprint globally, after they were in the first place in 2012 when Qatar topped the world in terms of its consumption and waste, recording a footprint of 11.64gha.

Earlier in 2010, Qatar's ecological footprint was measured with approximately 8.5 global hectares (gha), taking the second place after Kuwait having the world worst footprint over 10gha. Given the countries' small size, however, as the measure is based on per capita figures, their total impact is still relatively small and indeed are perhaps not an accurate reflection thereof, given the massive contributions from much larger countries such as China or the United States (Walker, 2014). The third was United Arab Emirates with 7.75gha, and Saudi Arabia, the world's largest oil producer, in 33rd position. The average global footprint per capita was 2.6 gha at that time (Kelly, 2014).

The above figures show the improvement in Qatar's and GCC situation throughout the years. However, for such small population and land area, Qatar's citizens' consumption habits stand out in a significant difference to those in most of the rest of the world. The country tops the world's least energy efficient nations per capita.

Carbon Dioxide (CO_2) Emissions

Different studies and reports highlight that despite of the relatively small geographical area of GCC countries, GCC countries have the highest carbon dioxide emissions per capita. Where the average resident generates from two to ten times the average global citizen's CO_2 amount. The next figure illustrates the GCC countries CO_2 emissions amount in tons per capita compared to the world in 2014 (Begum, 2014).

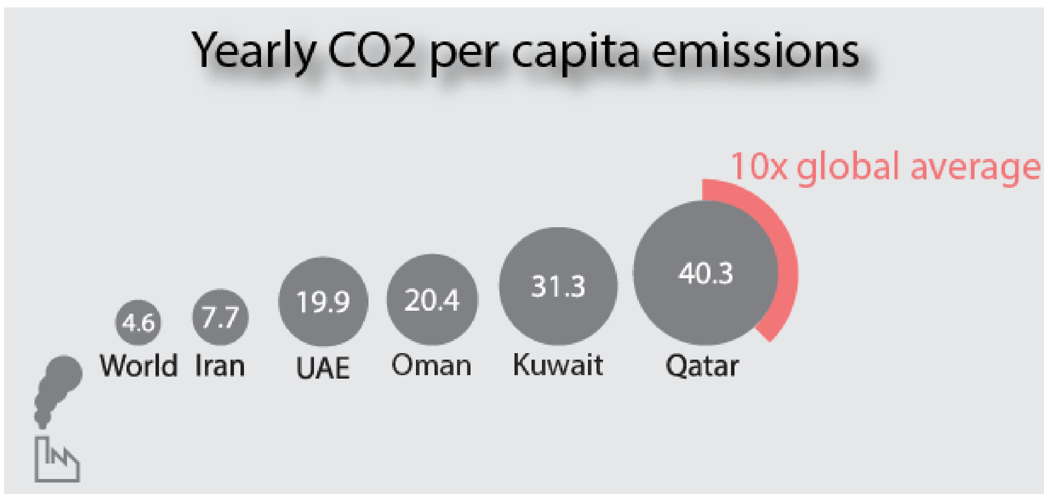

Figure 15. Yearly CO_2 per capita emissions. Figure Source: **(Begum, 2014)**

Qatar leads the CO_2 emissions per capita throughout the years. More than 70% of Qatar footprint was accounted by the CO_2 emissions resulting from the burning of fossil fuels. According to the most recent data by the US Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC), Qatar has the highest annual carbon dioxide emissions per capita. Carbon dioxide emission in Qatar reached an average of 41.5 tons per capita in 2012, 40.5 tons per capita in 2013, and 40.3 tons per capita in 2014 (List of countries by carbon dioxide emissions per capita, 2016).

Moreover, (Darwish, 2013) emphasizes that Qatar's carbon dioxide emissions is expected to increase about 6.6 times from 2000 to 2020 compared to 2.4 in Bahrain, 2.15 in Kuwait, 3.55 in Oman, 2.98 in Saudi Arabia, 2.83 in UAE, and 3.11 for all GCC. This increase associates the rising demand of electricity and fossil fuels affecting negatively on air and marine environment, and maintain their rate of CO2 emission per capita the highest in the world.

In electricity generation process, around 35% of fossil fuels is converted to electricity while the remaining 65% energy is converted into waste and lost heat transmitted in power plant generators and turbines. Thus, it's not surprising to know that the top contributor to global carbon emissions is electricity generation. The source of more than 50% of the global carbon emissions are electricity generating plants, according to International Energy Agency (IEA) (Khoury, 2012).

According to IEA latest data available in 2009 demonstrated in next figure, Electricity generation was leading other sectors including transportation that comes in the second place with 25% of the Middle East and North Africa carbon emissions, accounting for nearly 41% of the global carbon emissions. Approximately 70% of the Middle East and North Africa region's carbon emissions by electricity generation was mainly caused by Saudi Arabia, Egypt, the UAE, Kuwait, and Iraq together. However, this was in 2009 before having Qatar on top of the carbon footprint leading countries (Khoury, 2012).

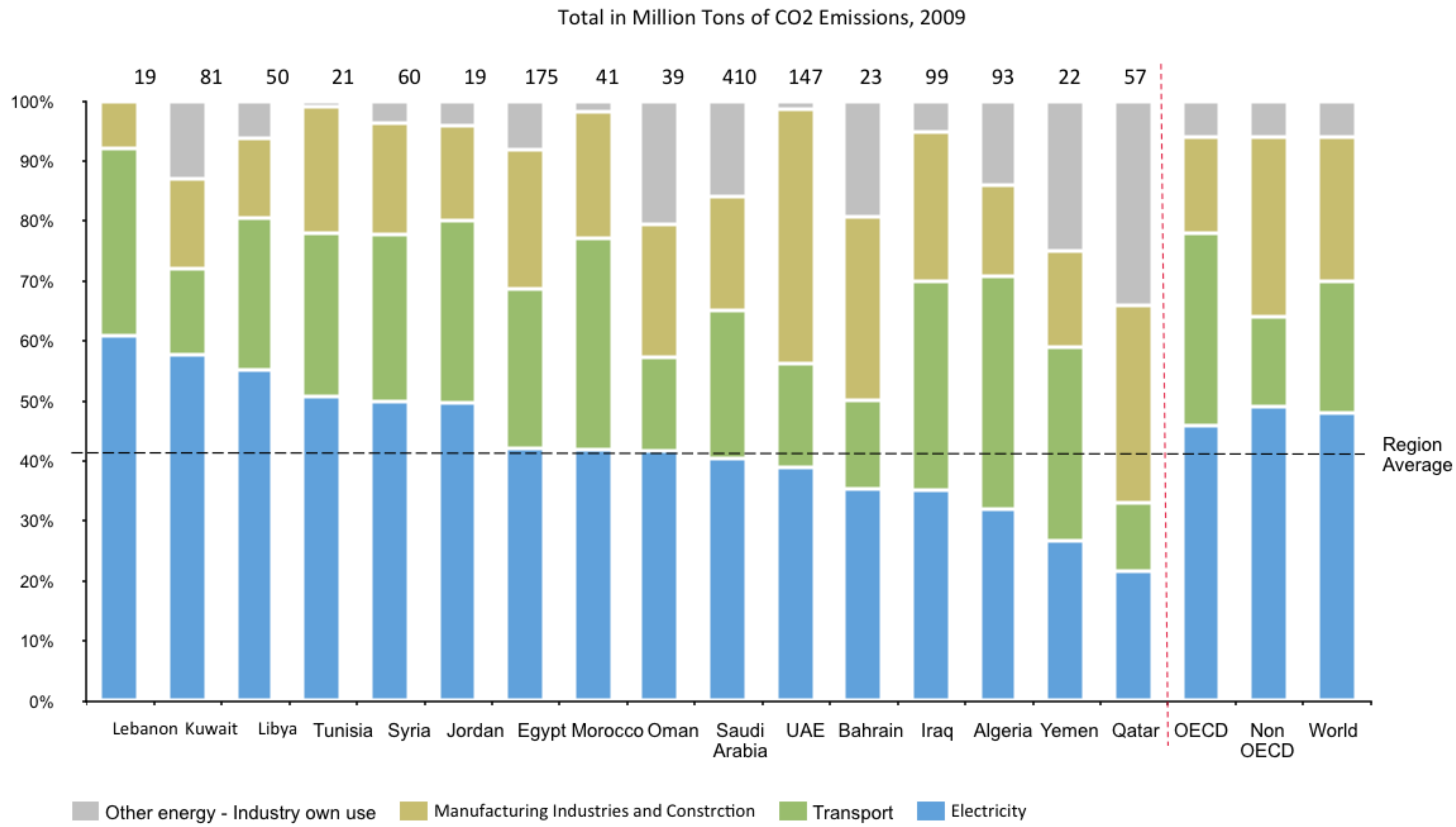

Figure 16. Total CO2 emissions by the Middle East and Africa in 2009. Image source: **(Khoury, 2012)** : http://www.carboun.com/energy/carbon-footprint-of-electricity-in-the-middle-east/

CHAPTER 4. LITERATURE REVIEW

As mentioned in previous chapters, due to several reasons that causes the state of Qatar to adapt policies that help reducing the domestic fossil fuels consumption in power generation and reducing CO_2 emissions, a study on neighboring GCC countries was conducted in order to find out more about the polices, regulations, and laws followed in order to be able to meet the increasing demand in energy throughout clean renewable sources.

Section 4.1 United Arabs Emirates Policies:

Since the UAE has the advantage of the geographical position, the solar energy is easy to be obtained. Studies confirm that solar potential is high in the UAE. According to several studies, the use of PV in the UAE is one of the m.ost promising and reliable technologies. A study has been conducted by the petroleum institute in Abu Dhabi, to study the Global Horizon Irradiance (GHI) on several locations in the Emirates from 2007 to 2009. Values were computed and collected hourly daily and monthly. Results has shown a high percentage of clear days during the year and the average annual number of GHI is above 500 W/m2, six hours a day, which proves that applying PV in the city of Abu Dhabi is technically feasible.

Currently the government of Abu Dhabi has set a Quota system having 7% of electricity generation is from renewable resource. Solar energy is favored as a renewable source in Abu Dhabi. There is a plant already installed and operating producing 10 MW PV. A study done by "Mezher, Dawelbait, & Abbas, 2012" has recommended to have a mixed policy between FITs and Quota system in order to share electricity generated. It has been recommended that in order to ensure the policy to consider the following:(Mezher et al., 2012)

- There has to be a strong political well in order to continue in this direction and not to be influenced by the power system or the cost of electricity.
- Through Masdar initiative, the main RE technology is wind and solar.
- The UAE's target in the future is 7% and it can be increased.
- Must insure that ASWEC the main electricity provider to buy the electricity generated from RE, while the power transmitting company Transco, provides the grid connection of all RE sources. (Imen, 2012)

Section 4.2 Saudi Arabia Policies:

Saudi Arabia is the largest in area among the GCC countries, with total area of 2.15 million km2. A study by King Fahd University has estimated that the country's average annual GHI value at 2,139 KWh/m2/year. Another study have been conducted in order to find the average distribution wh/m2/year solar radiation over the country, the study has resulted that the mean GHI was 2.06 MWh/m2/year. Different locations were studied and the studies have showed ranking of the locations. It was found that the best place to installed PV system is Bisha and the worst is Tabuk. In addition to the average photovoltaic annual energy production was 10 GWh and it was 23% efficient, and the average COE is approximately $0.25/KWh.

Realizing that the demand on electricity will grow drastically in the next 10 years, Saudi Arabia has been investigating alternative resources to satisfy the future needs. In 2011, it has been announced that a $100 billion will be invested in order to expand power generating capacity, including of nuclear plant and the deployment of 5GW of solar energy capacity by 2020. (Imen, 2012)

In order to encourage the private sector, and the general public to operate access or own a solar energy technology, Saudi Arabia should consider introducing a specific financial incentives, like local credit system or RE subsidies. Increasing the awareness of the public can lead large users like hotels, hospitals or industry to reduce the consumption of crude oil generated electricity. (Imen, 2012)

Section 4.3 Kuwait Policies:

Due to the different and harsh weather conditions in Kuwait, it was more difficult to install a PV system and get a high efficiency. Thus studies have confirmed that a high level of insulation combined with high percentage of sunshine hours provide a good enough condition for generating electricity using PV in Kuwait. Installing the system on 25 sampled houses, where computer simulations were used to calculate the electricity generated it was come to a conclusion that PV system installed on average residential house in Kuwait, will produce annually 148,039 kWhr/year.

The value of annual production of the PV system is higher than the consumption in an average house in Kuwait. (Imen, 2012)

Kuwait may lack a cohesive renewable energy technology strategy, however the country is trying a different approaches in order to build up an effective plan locally for the development of such resources. Some of the RE technologies in their country will depend on:

- Non- discriminatory policies to attract investors.

- Integration of the RES option(s) into energy policies, scenarios and cross-border trading, as part of a portfolio of energy sustainability measures;
- Enabling RES laws and regulations on licensing, commissioning, safety and liabilities;
- International cooperation and technology transfer as well as acceleration of R&D, in particular on the viability of technology;
- Building of several cost-effective large-scale demonstration plants; and
- Allowing involvement of all stakeholders in decision-making on energy trading and technology implementation.

Section 4.4 United States Policies

The difference between the US market and other nations is that the US energy regulations are different from a state to another, rather than unified national regulations. Likewise, electrical companies work on a state level rather than working nationally. Thus, the policies function differently from a state to another based on the state needs and aims.

The united states policies were analyzed and studied in different states in (Burns & Kang, 2012) and it can be summarized in the following:

- Tax credits: The federal "Residential Renewable Energy Tax" is a personal tax credit that is non-refundable and only applies to the residential renewable energy systems. The federal government allows the installation of solar PV a one-time credit equivalent to 30% of the cost of installation. The price of installation includes: on site preparation, equipment, labor cost, assembly or original installation, and piping for connection with grid.

- Cash rebates: which are dollar amounts of cash paid per watt-capacity of the solar PV installed. They are paid out on basis of first com first serve, thus it can be an issue in case of lack of funding.
- Net metering: the simplest incentive renewables is net metering. This allows customers to offset their electricity use by the amount of energy generated by their integrated system.
- Renewable portfolio standard (RPS): the whole spectrum of renewable energy is covered by the RPS, and variation depends on the state itself. Similar to the Tradable Green certificate (TGC), the states require utilities companies which deal with renewable energy certificate (REC) which is equivalent to 1 MW of energy which created from renewable sources.
- Solar set asides: the term set-aside refers to a provision within the RPS requires companies to use a specific renewable source, in order to account for a specified percentage of their retail electricity sales according to a set schedule.

Section 4.5 Other Policies:

Feed-in tariffs (FITs): the term feed in tariffs is derived from the German term which literally translates to "electricity feeding-in law". Germany has implemented the feed in law in order to create a market for renewable electricity by offering a fixed but attractive price to providers for the recovery of the generation costs.

Centralized bidding or Tendering: this policy was applied in the early stages of development of renewable energy in the UK, and is employed nowadays in the wind power in china under the name concession program. The policy mechanism calls for bids from inventors for RE projects. This policy aims to find the lowest possible cost projects which develop RE.

Renewable obligations (RO), Mandatory Market Share (MMS), also known as Quotas: these are all different name for the same policy which is similar to the RPS policy in the United States. The shared property of all these incentive is that the government sets a certain percentage for the electricity generated by renewable resources, assigning electricity generation companies, whether they were suppliers or generators, to meet the specified percentage by the government and penalize those who don’t meet up with the assigned value. Even though this method have resulted in growth of the RE using countries but wasn’t as successful as the FITs which is used in Germany and Denmark.(Mezher et al., 2012)

CHAPTER 5. RENEWABLE ENERGY DEPLOYMENT IN QATAR

The production of electricity and water has been growing in a very fast pace, around 80% in the past five years. The peak of the demand has increased by 10.7% in the last 7 years. In 1999 the electricity, water, transmission and distribution services were all done the ministry of water and electricity. Qatar has open the door for private companies in 2000, in order to encourage the privatization of the production of water and electricity. Thus, many establishments has taken a step forward to form new organizations such as Qatar Electricity and Water Corporation (QEWC) and other independent power and water providers (IPWP), therefore, the private sector investors in addition to international developers has had the chance to develop a major role in building up significant generation capacity in the country. After the dissolution of ministry of electricity and water, another company has taken the responsibly to continue the work of the ministry which is called KAHRAMAA. In addition to many other roles, KAHRAMAA has the task of implementing new projects. However with the increasing demand of production, Qatar is under pressure to prepare for an average of 1000 MW additional capacity every year in order to satisfy the demand.

Qatar is characterized with the very high temperatures due to the geographical position. High evaporating rates, very strong wind and relative humidity. The availability of solar energy in Qatar has been analyzed in several studies, and results suggests that the implementation of solar technologies could be very beneficial for the country.

Development, research, and business feasibility planning, is the approach of Qatar to develop the resources of renewable energy. Several studies are being conducted in

Qatar relating the energy and environmental issues. Recently, one of the German companies based in Qatar, Heliocentric energy Solutions, has agreed to provide practical knowledge by establishing a solar and wind energy generation systems and storage, including fuel cells and hydrogen technology, this example and many more proves that Qatar's aims to diversify its industry in order to enhance the scientific and knowledge base of its economy. Another example of the constant activities in the field of improving the understanding of clean energy production, the Chevron Corporation and QSTP agreement on establishing the Chevron Center for Sustainable Energy Efficiency (CCSEE) which aim to develop and research the application of the low energy lighting technologies, solar cooling, and solar panels to the middle east's climate. $20 million we planned to be invested in the project in 2009 and over 5 years to fun the center. The center has announced of collaboration between the universities in the city of education, QSTP tenants, and other local developers to work on training young engineers, scientists, and students from Qatar to help them create experts are capable of understanding the implementation and the importance of solar energy.

Only until recently Qatar has started paying attention to the potential it has for production of renewable energy, and took some steps in the development path of RES not just on local but also on international level. In 2009, Qatar has signed to join International Renewable Energy Agency (IRENA). In addition to announcing the ministry of energy and industry that it is going to examine the potential of renewable resources by forming a committee in Qatar. Meanwhile on the environment front, Qatar has adopted Agenda 21 of the United Nations Conference on Environment and Development, which calls the commitment of the state to institutionalize environmental impact assessment among other things for the new projects development. A policy has been arranged for the Environmental Impact Assessment of major infrastructure projects.

Qatar has the ability to invest in renewable energy sector, according to experts, in order to encourage national low carbon dioxide economy. It has been recommended that Qatar's sovereign wealth fund Qatar Investment Authority (QIA) participate with the maker of policies to discuss ways of improving complete investments in this sector and associated Clean Development Mechanisms. National policies are needed to balance intensive economic growth based on energy, in order to ensure sustainable social development. These policies to reduce the impacts on human, economic and environment, which will lead in shortages, inherited ecological disruptions and extended social damages.

Qatar, yet, has not defined any goals for RES involvement to its energy diverse future nor has it established broad adjusting framework for RES investments. Deployment of solar and wind energy has been nonexistent in Qatar except for the technological R & D or industrial projects.. (Imen, 2012)

CHAPTER 6. POTENTIAL OF SOLAR PV IN QATAR

The following points explain the reasons of selecting solar PV as a good potential method in solving the energy challenges addressed in **Error! Reference source not found.** and the advantages of this method.

1. *Solar Radiation Region & Endless Source of Energy*

Qatar's dry and hot desert climate and its location make the solar energy an abundant source of energy in all days of the year. Temperatures in Qatar reach its maximum in summer season from June to August reaching high 50ºC (122ºF), and average temperature around 42ºC (108ºF). Temperatures are cooler in the winter months from December to February but still warm, with the average around 23ºC (Qatar Weather, climate and geography, 2016). Qatar receives approximately an average of 2048kWh/m^2 of global horizontal solar irradiation annually according to actual ground measurements from 2008 to 2012. As shown in **Error! Reference source not found.** from (Global Horizontal Irradiation (GHI), 2014), the solar radiations range from 2050 to 2150 kWh/m^2 which considered high range. The range gradually increases as you go towards the southern borders with KSA. This high radiation level makes solar energy an attractive renewable resource for energy in Qatar. The availability of the sun energy all over the year and the strong association between the high radiations and cooling and electricity demands makes this source of energy the most attractive renewable resource for electricity generation and cooling.

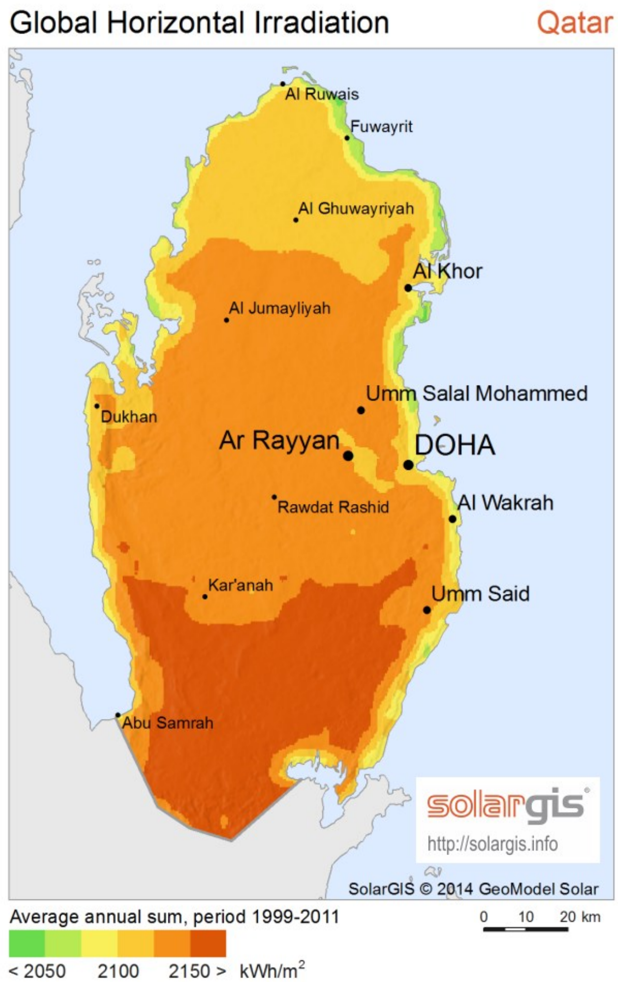

Figure 17. Solar irradiation in Qatar in 2014. Figure source: (Global Horizontal Irradiation (GHI) http://solargis.com/products/maps-and-gis-data/free/download/qatar

2. *Technology used in PV Module*

Crystalline silicon-based systems are the most PV technology established. This module material represent about 10% of the global market. The main two advantages of PV module technology are; one, the large manufacturing and production rates as the small module can be manufactured in large plants, allowing economics of scale. Two, PV modules can be used in small quantities allowing the diversity of applications from residential scale power generation up to utility scale power generation facilities (IEA, 2014).

Different available technologies such as the Concentrating Solar Power (CSP), Concentrating Photovoltaic (CPV), and Non-Concentrating PV also enables a wide range of alternative solutions and applications. The Non-Concentrating PV has a good advantage in allowing effective deployment in many regions as it can be used even if the sky is not fully clear (IEA, 2014).

As highlighted by (IEA, 2014) The solar PV technology is spreading quickly ranked as the second largest energy source capacity where around 128 GW of solar PV capacity was installed in 2013.The coming figure shows the Solar PV electricity generation and forecast by region according to (IEA, 2014), Medium-Term Renewable Energy Market Report 2015.

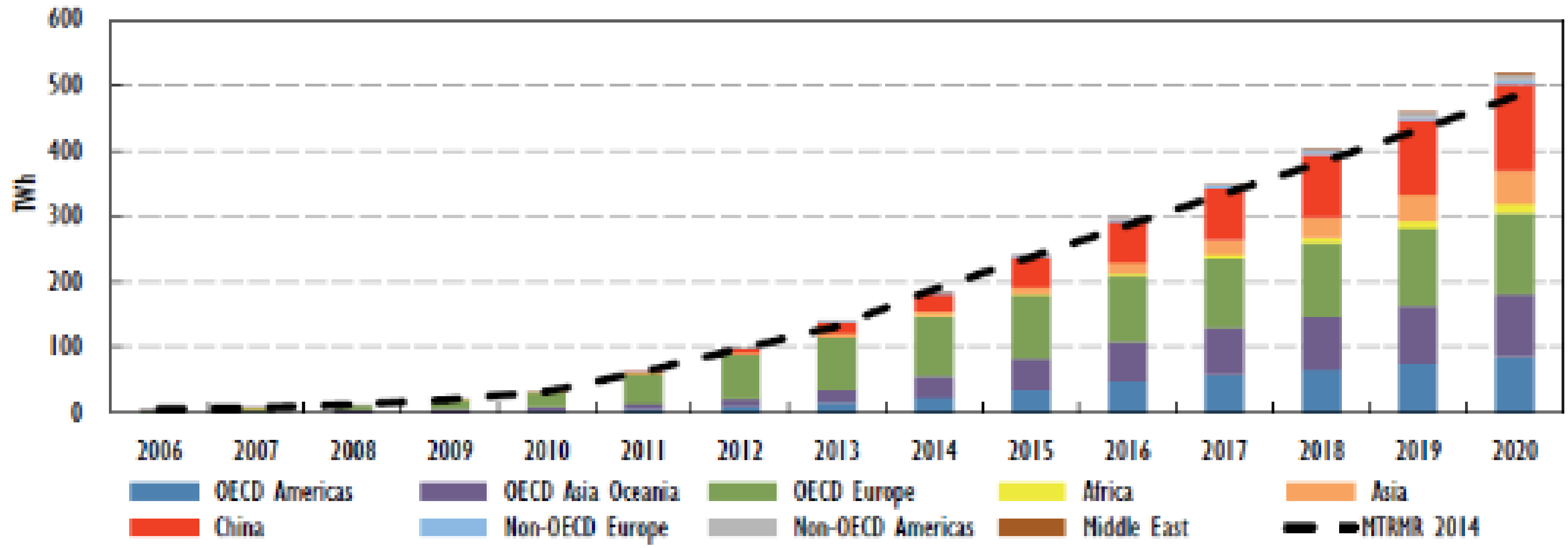

Figure 18. Solar PV electricity generation and forecast by region according to (IEA, 2014), Medium-Term Renewable Energy Market Report 2015.

3. Dramatic Reductions in Solar PV Systems Market Prices

The following figure shows the dramatic declining price of one PV module type (Chinese c-Si) from 2008 to 2011.This decline was not limited to the Chinese PV only, it was for all PV industry at that time as emphasized by (Bazilian & Onyeji, 2013). The sharp reduction was associated to the decline of the basic module material - polycrystalline-silicon - prices, market and manufacturers competency, the improved experience curves, and the emergence of the Chinese manufacturers. The module price declined from around $4.00/W in 2008 to almost lower than $1.00/W in 2011, according to a study conducted in reconsidering the economic power of PV in 2013, (Bazilian & Onyeji, 2013). Moreover, a 22% decrease in the module price occurred in 2013 compared to previous year as stated by (IEA, 2014)

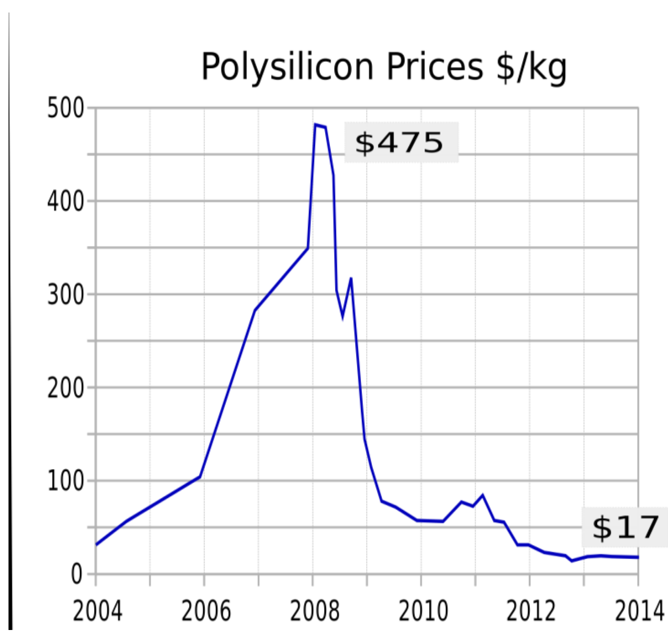

Figure 19. Price trend of the Polysilicon material in $/kg. Figure source: (Wikipedia, 2014)

(Bazilian & Onyeji, 2013) also stated that the silicon material cost drop from more than \$450/kg in 2008 to \$27/kg in 2012 has significantly impacted the PV module price as is it approximately account for 20% of the total module price. The next figure shows the price trend of the Polysilicon material in \$/kg reaching its minimum value of \$17/kg in 2014. (Wikipedia, 2014)

The module price dropped more than 50% in one year between 2008 and 2009 as shown in the figure, however manufacturers were able to make positive operating margin, (Bazilian & Onyeji, 2013). This was because of the associated drop in the manufacturing costs due to the improved process and technology understanding and experience, in addition to the improved cell performance and falling installation and maintenance costs.

Although many PV buyers and policy makers would consider the current PV module price economically unattractive compared to the existing conventional power generation options, all the figures and studies indicate that the price of PV modules will continue declining as the technology and manufacturing process continually improve, suggesting the PV technology as one of the best potential methods in the upcoming era. (Elhadidy & Shaahid, 2008)

4. Industrial Diversification & Job Opportunities

The solar energy deployment contributes to the economic growth in terms of net economic output and overall employment. Solar Energy adoption adds a significant advantage to the local economy at large, especially if deployed in the right way and on a large scale locally. Deployment of solar energy offers the potential for related industry establishments as well as creation of new range of green job opportunities, imposing a forward and backward linkage to the economy scale. According to the UNDP, renewable energy provide more job opportunities per unit of installed capacity, per unit of power generated, and per dollar invested, more than the fossil fuels power plants. The next figure shows the employment growth between 2010 and 2014 in the US solar related industry associating the solar energy deployment growth, provided that employment in the solar energy industry grew by more than 85 percent in the same period. (The Energy Revolution, 2015)

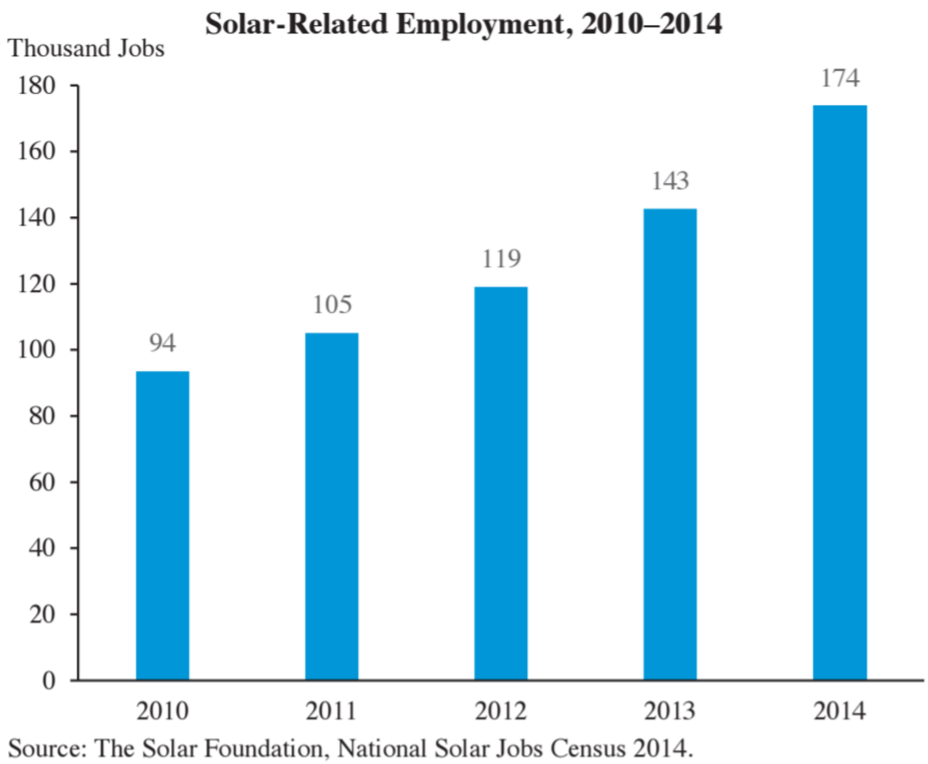

Figure 20. The employment growth between 2010 and 2014 in the US solar related industry associating the solar energy deployment growth. Figure source: **(The Energy Revolution, 2015)**

As Qatar is devoted to enhance the career future of its citizens and provide a wide range of the white-collar job opportunities for its young and increasingly educated citizens, the deployment of solar energy supports this mission by the job opportunities created that include jobs in engineering and technology specialties corresponding well to the type of jobs that Qatar is interested in. (The Energy Revolution, 2015) (El-Katiri & Husain, 2014)

The new renewable industry innovative technologies in addition to the new R&D opportunities created by solar energy deployment, fits well with the objectives of existing GCC policy of creating more local jobs Also corresponds the current status of the region as a center of multiple technologies. Moreover, these technology options offered by solar energy have no political arguments attached unlike the nuclear energy technologies, as it is mature and easily transferable. (El-Katiri & Husain, 2014)

5. *Increasing Fossil Fuels Exports*

Adopting solar energy in power generations would also have a significant impact on the fossil fuels - natural Gas more specifically - production. Hence, impacting the country's net economic output. Reduction in the domestic natural gas consumption in electricity and power generation helps in increasing the natural gas production as the main revenue-generating export. This alternative energy supply - Solar energy- has a strategic role in increasing and securing the natural gas and other energy fuels exports, hence the fiscal stability of the country in large. (The Energy Revolution, 2015)

6. *Environmental Benefits*

In addition to the above mentioned economic advantages, renewable solar energy technologies also can provide extra benefits to Qatar and the GCC states as alternatives to the oil and gas in the environmental policy.

Although environmental considerations have not been part of the traditional policy concerns in the GCC region for long time including the approach of avoiding any debates regarding the climatic changes; considering the environmental harmful effects of the reliance on gas/fossil fuels based power generation and considering the possible environmental and economic advantages offered by the alternating resources is a good reason for improving the traditional policy approach. The environmental situation of Qatar is known as explained earlier in this report, however it has been met with not enough political attention. (El-Katiri & Husain, 2014)

As Qatar and other GCC states committed to reduce their carbon footprint with the aim of complying to the Kyoto protocol provisions, renewable solar energy technologies can play an important role in addressing the carbon emissions and other environmental issues. Hence, important policy arguments and decisions can be generated by considering the environmental and economic benefit of the solar energy technologies. The increasing energy demand and pollutions and emissions levels concerns are considered important arguments in favor of justifying the investments in solar energy technologies as a long term solution despite of its expensive cost, in addition to the benefit of saving energy at the consumer level. (El-Katiri & Husain, 2014)

CHAPTER 7. ECONOMICAL ANALYSIS OF PV SYSTEMS AND PROPOSED POLICY

In this Chapter, cost and economic analysis from the customer perspective are introduced based on PV system installation calculations and assumptions. The Net Present Value (NPV) of the system is presented based on a set of assumptions and available data. Also a sensitivity analysis using on Monte Carlo simulation is provided in this chapter, exploring the different behaviors of the PV system's NPV when varying different input variables.

Section 7.1 Solar PV Cost and Economic Analysis

In this section, the used data resources and PV system related specifications available in appendix. In addition to the detailed calculations for the presented figures .The following table summarizes the PV system assumptions:

Table 2. Assumptions for PV system calculations

PV installation cost for 1kW system	$1,055
Operation & maintenance cost	1% of system installation cost annually
Inflation rate	0%
Discount rate	6%
Module efficiency	25%
System useful life	25 Years
Operation hours	8 hours/day
Operation days	325 days/year
System efficiency in first 10 years of operation	90%
System efficiency from year 11 to year 25 of operation	80%

The following table shows the different NPVs obtained for different electricity tariff prices, based on the assumptions in the above table and with no subsidy introduced. The NPV increases as the tariff rate increases from QAR 0.08/KWh to QAR 0.22/KWh. The table also shows that the NPV becomes positive as the tariff rate increase above QAR0.18/KWh.

Table 3. NPV at different tariff rates. Detailed calculations in appendix

Tariff rate in $	0.02	0.02	0.03	0.03	0.05	0.06
Tariff rate in QAR	0.08	0.09	0.10	0.12	0.18	0.22
NPV in QAR	(2,297.76)	(2,028.87)	(1,759.97)	(1,222.18)	391.20	1,466.79

The above table figures calculated considering the initial installation cost of the 1KW system assumed in Table 2.However, considering the change of +/-10% and +/-20% in the assumed installation cost would result in changing the NPV in QAR as shown in the next table:

Table 4. NPV in QAR for different system installation costs and tariff rates. Detailed calculations in appendix

Installation cost			Tariff rate in $ and in QAR					
Change	QAR/kWh	$/kWh	$0.02	$0.02	$0.03	$0.03	$0.05	$0.06
			QAR 0.08	QAR 0.09	QAR 0.10	QAR 0.12	QAR0.18	QAR0.22
			NPV in QAR					
-20%	3072.16	844	(1,407.98)	(1,139.08)	(870.18)	(461.07)	1,280.99	2,356.57
-10%	3456.18	949.5	(1,852.87)	(1,583.97)	(1,315.08)	(777.28)	836.09	1,911.68
0%	3840.2	1055	(2,297.76)	(2,028.87)	(1,759.97)	(1,222.18)	391.20	1,466.79
10%	4224.22	1160.5	(2,742.65)	(2,473.76)	(2,204.86)	(1,667.07)	(53.69)	1,021.89
20%	4608.24	1266	(3,187.55)	(2,918.65)	(2,649.76)	(2,111.96)	(498.59)	577.00

The data in Table 4 show that the NPV increases as the installation cost of the system decrease and tariff rate increase, reaching the maximum value of QAR 2,356.57 when the system cost is less by 20% ,in other words when the price of the system reaches $844 from its current cost of $1055, and for tariff rate of $0.06/KWh (QAR 0.22KWh).The table also shows that the lowest NPV is -QAR 3,187.55 at system cost of $1266 (20% higher than assumed current cost of $1055) and tariff rate of $0,02/KWh (QAR 0.08/KWh).The next figure is a 3D illustration, showing the NPV changes for the different system installation costs and tariff rates:

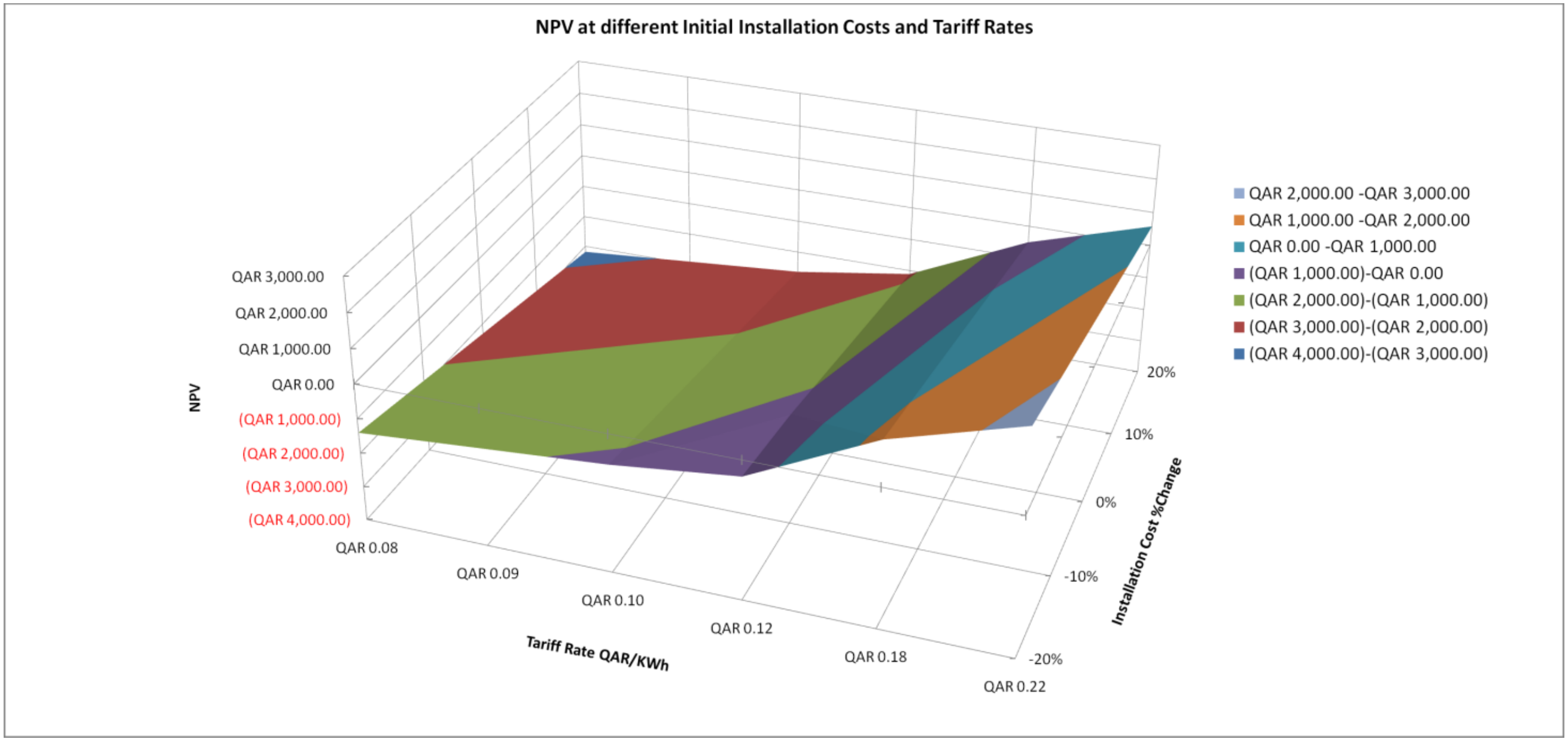

Figure 21. NPV at different initial installation cost and tariff rates

For further analysis and to be able to estimate the subsidy amount that should be provided as well as the targeted customers range to make the system more attractive improving the NPV value, next figure constructed by calculating the NPV for different subsidy levels. Subsidy values varying from zero to QAR3000/KWh inserted in the NPV equation, considering the different tariff rates (QAR 0.08/KWh to QAR 0.22/KWh) and system installation cost of 0% change (hence $1055) .The resulted 3D graph illustrates the behavior of NPV under the provided conditions. Data tables and calculations in appendix.

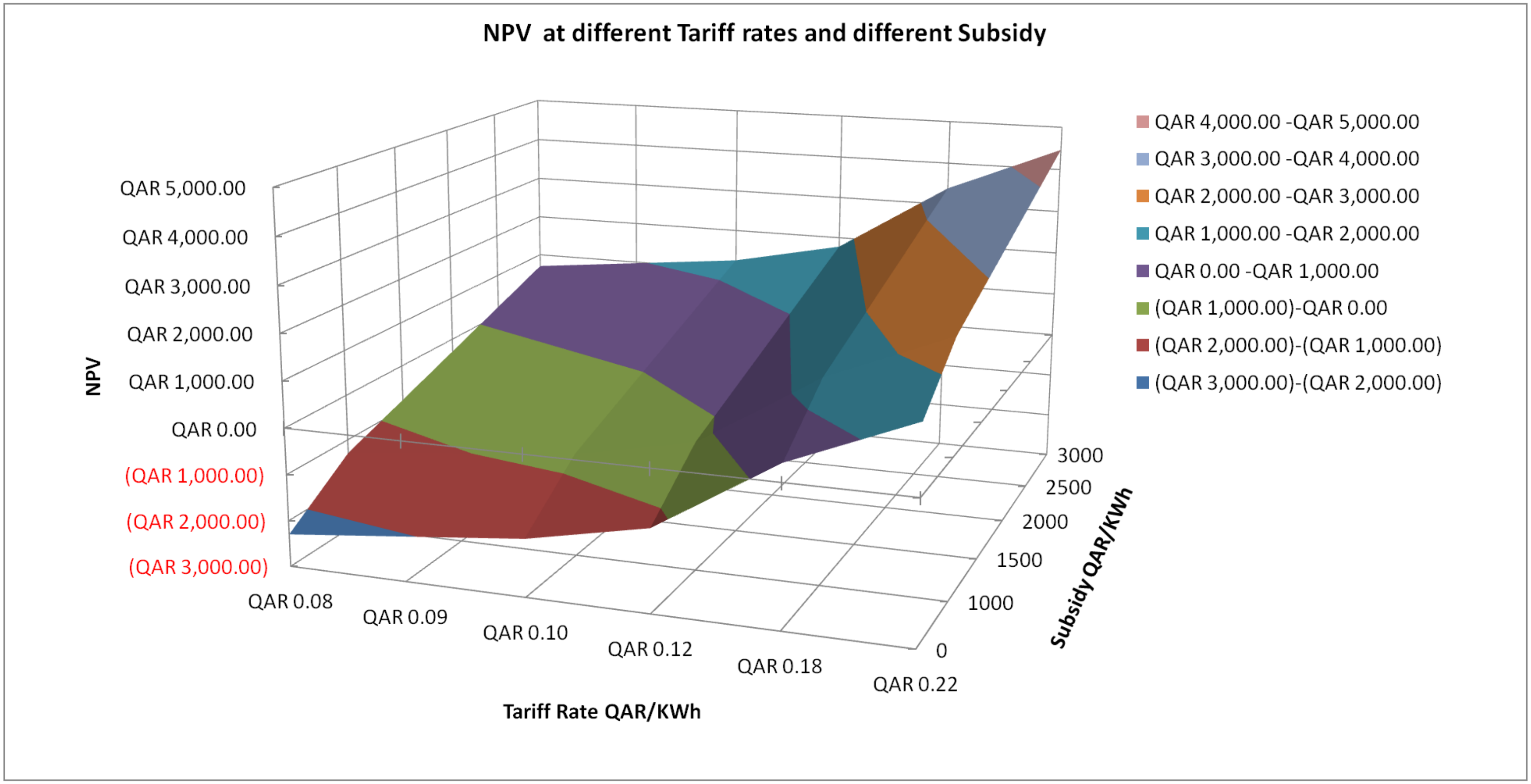

Figure 22. NPV at different tariff rates and different subsidy levels

The results in above figure show that NPV improves for higher tariff rate or higher subsidy level or both together. At a subsidy value of QAR1500/KWh and tariff range above QAR 0.1/KWh the NPV becomes -QAR 259.97 increasing to positive values as the tariff rate increases to QAR 0.22/KWh, hence the system becomes more feasible for the consumers in this range. This helps in identifying the targeted consumers' population for the proposed policy in next section.

Section 7.2 Sensitivity Analysis

In this section Monte Carlo simulation of 100,000 iterations is applied on a 1 kW system by varying four NPV function inputs, for a zero subsidy amount. This helps in analyzing the NPV behavior with wider range of inputs variations. The following figures summarize the four used input variables and the assumed distributions. Refer to (Table 18. Simulation model input summary) in **Error! Reference source not found.** for more details.

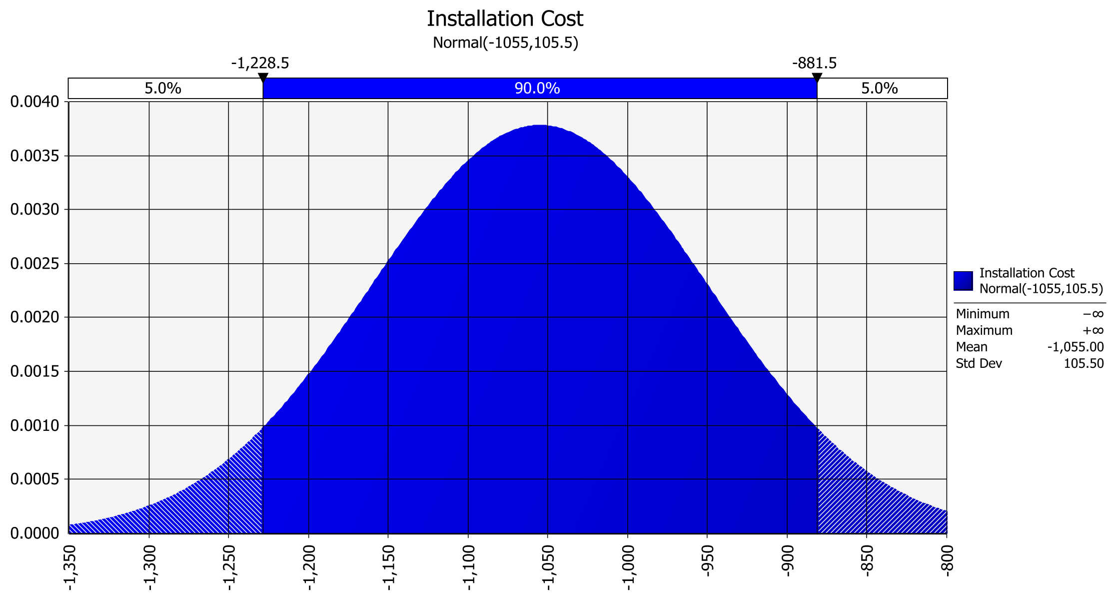

Figure 23. Installation cost data distribution for sensitivity analysis simulation

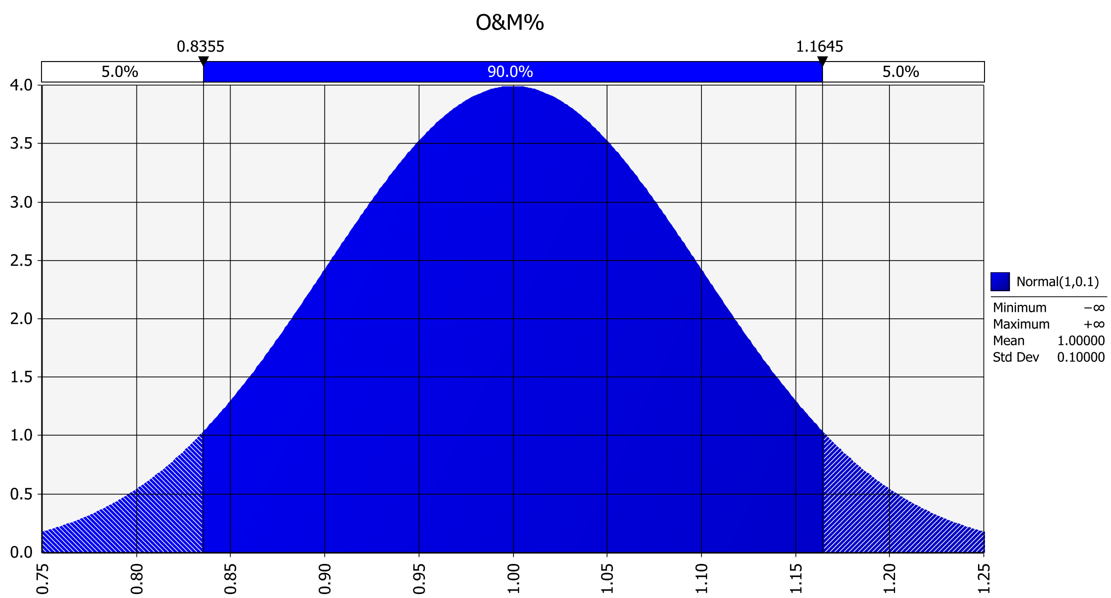

Figure 24. Operations and maintenance % change distribution for sensitivity analysis simulation

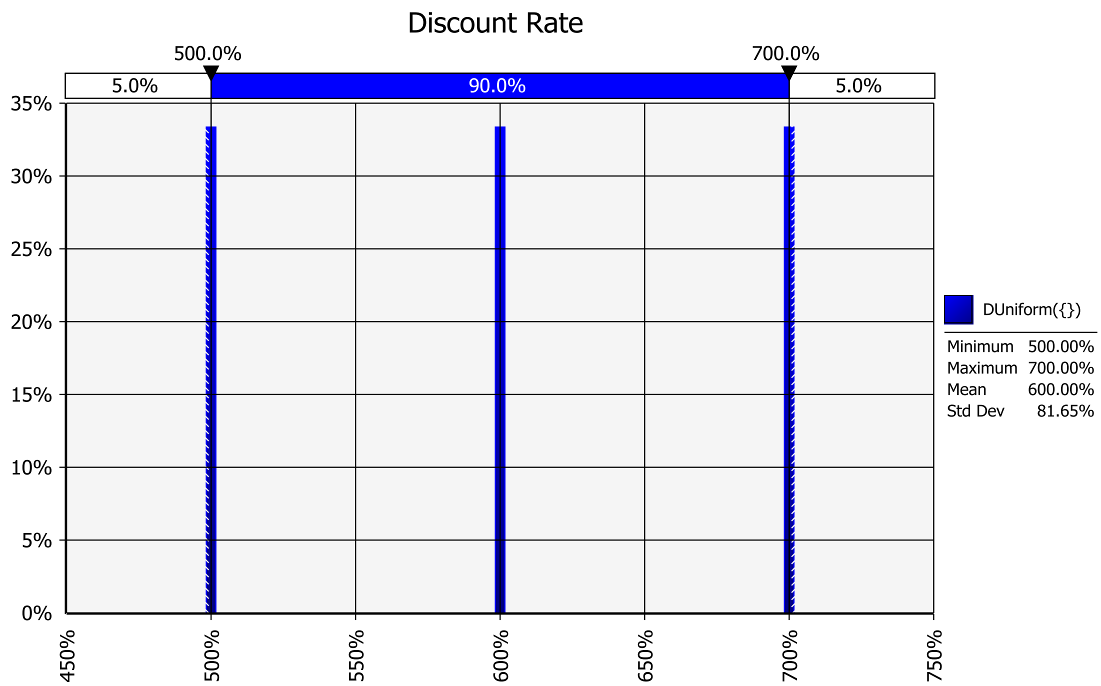

Figure 25.Discount rate data distribution for sensitivity analysis simulation

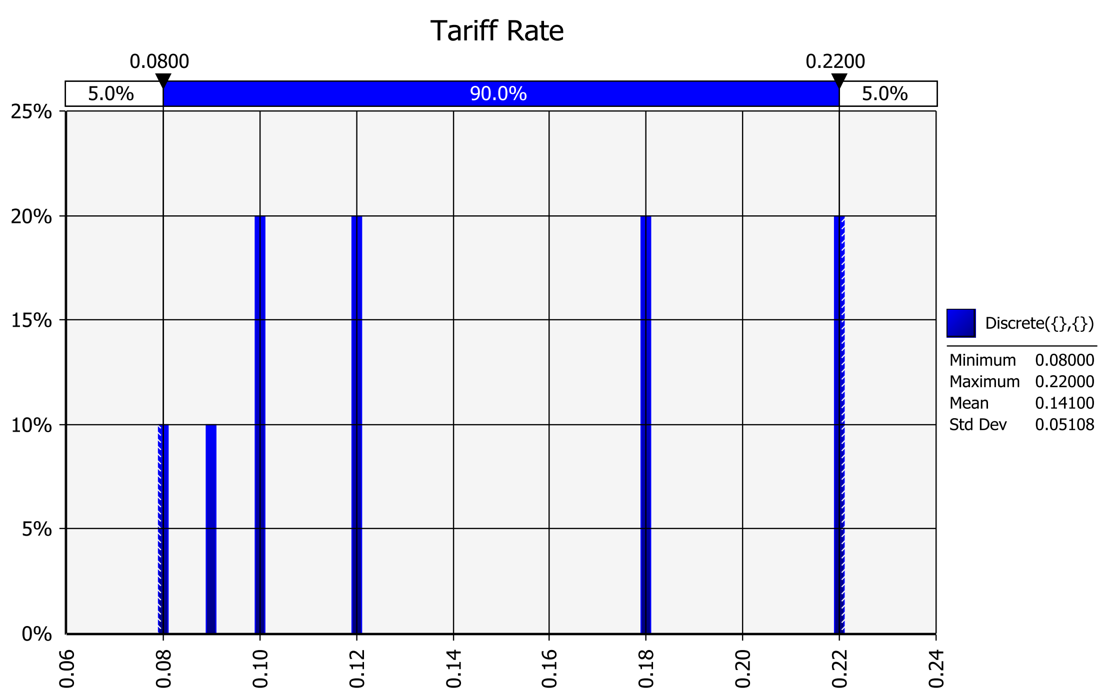

Figure 26.Tariff rate data distribution for sensitivity analysis simulation

The following figure illustrates the simulation output of 100,000 iterations. Showing the probability density of the NPV results with a maximum value of QAR 3,736.85 and minimum value of -QAR 4,139.48. The mean value is -QAR 642.33 and median -QAR 1093.04, statistics summary in Table 20 in **Error! Reference source not found.** As shown in the figure, 90% of the results were between –QAR 2,550 and QAR 1,921

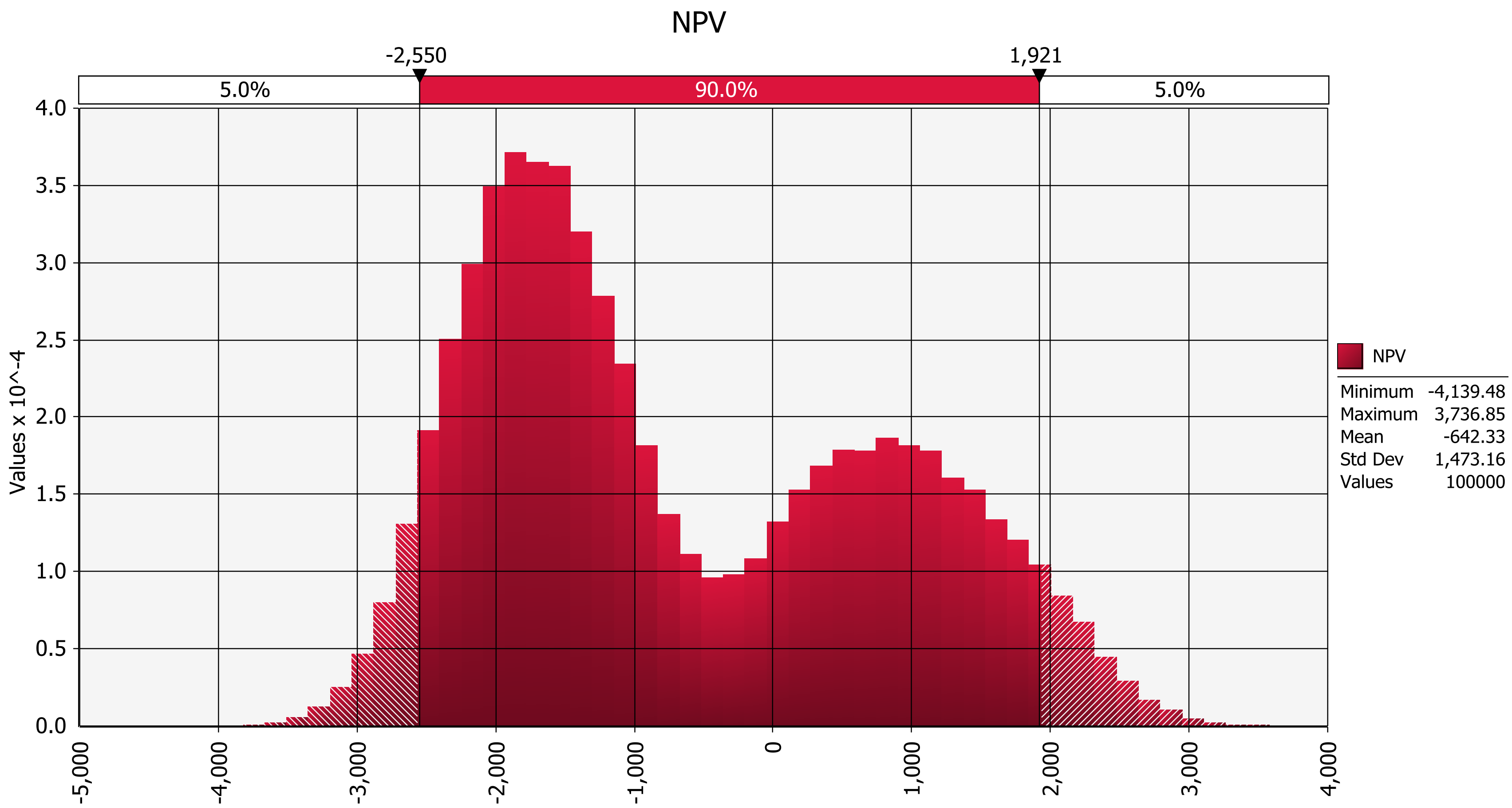

Figure 27 NPV probability density distribution, output result by the Monte Carlo simulation for 100,000 iterations (zero subsidy)

For the same simulation results, the following two figure shows that approximately 50% of the NPV results fall between –QAR 2,550 and -QAR 850, and 30% of the results fall between QAR100 and QAR 2,000.

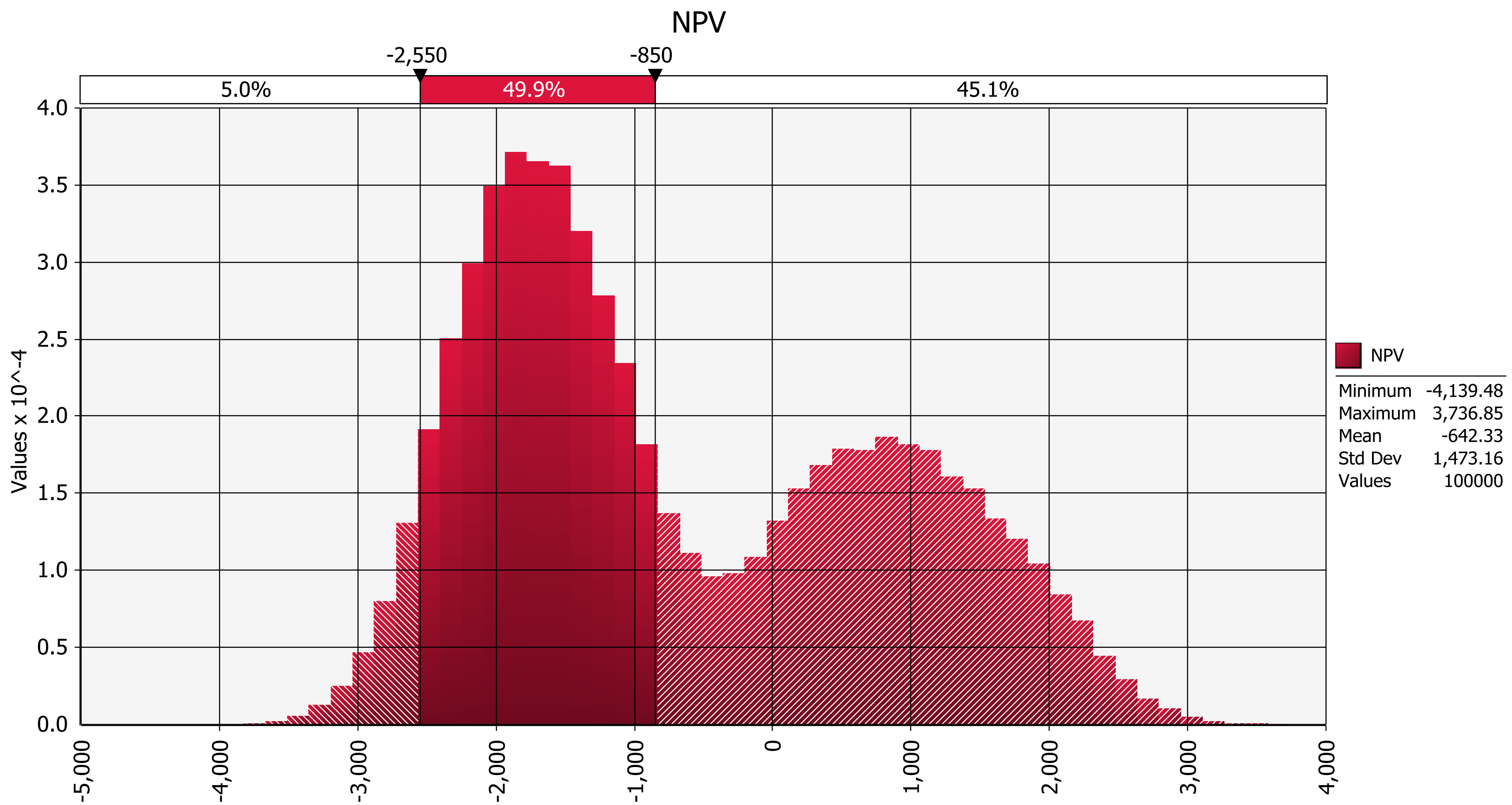

Figure 28.NPV probability density distribution for the NPV range (-2,550 to -850), output result by the Monte Carlo simulation.

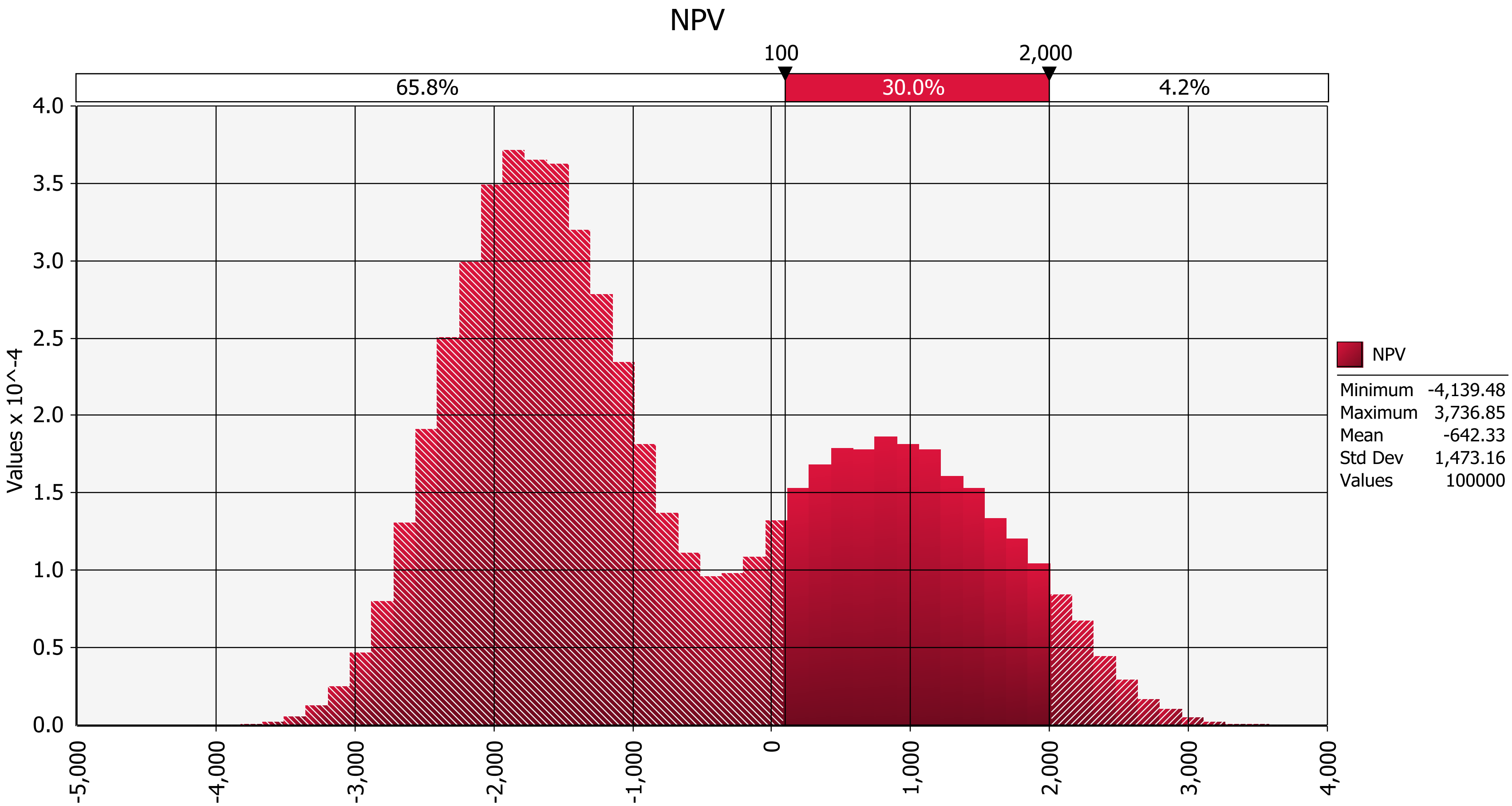

Figure 29.NPV probability density distribution for the NPV range (100 to 2,000), output result by the Monte Carlo simulation

The next spider graph shows the impact of the four inputs on the NPV output, as shown the tariff rate has the highest impact on the NPV output change. The Operations & Maintenance (O&M) and the discount rate have very low impact that is almost insignificant, and the Installation Cost comes in the second rank after Tariff Rate.

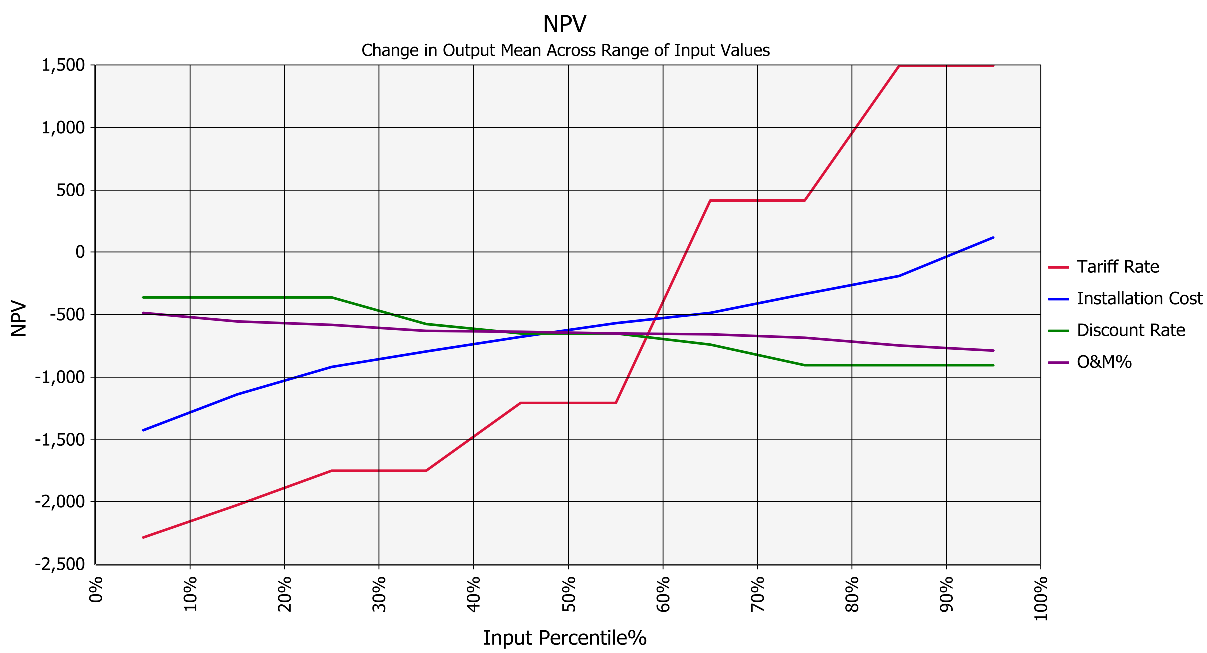

Figure 30.Spider diagram illustrates the different NPV simulation inputs and their variation impact on the simulation output mean (NPV mean)

Another figure shows the ranking of each input variation significance is presented below.

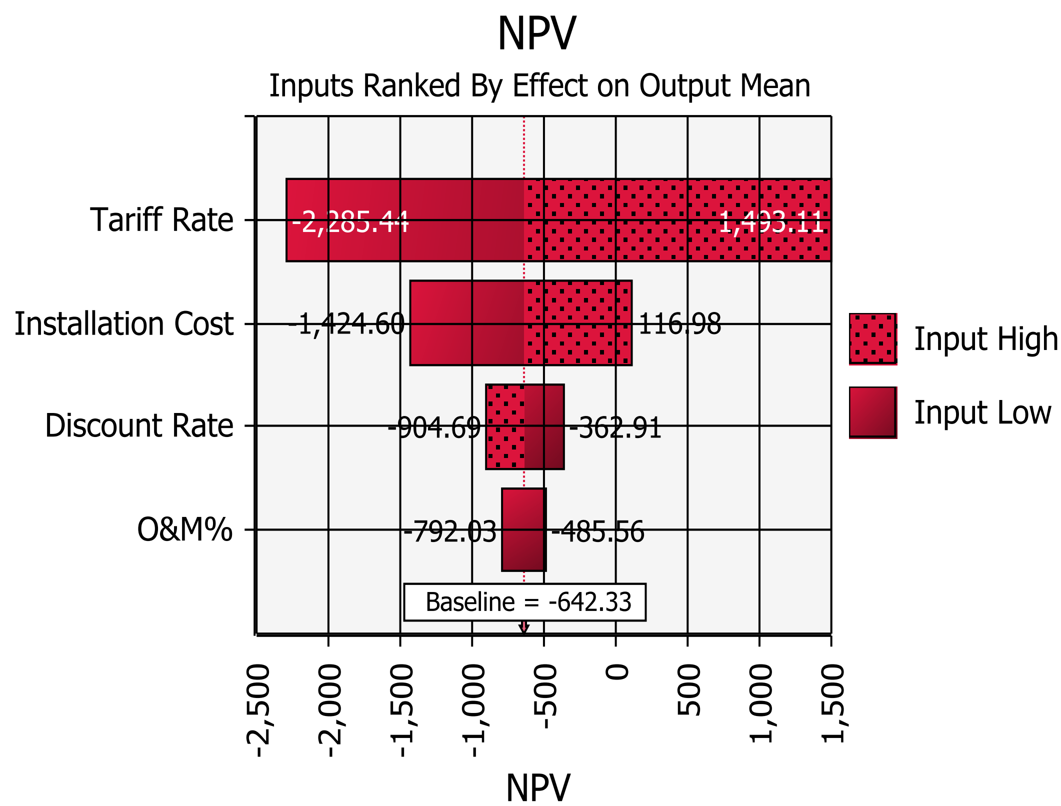

Figure 31.Turnado diagram illustrates the effect of the simulation input variables changes on the simulation output mean (NPV), ranking inputs from the highest significant impact to the least

Another simulation performed with the same input distributions but this time a QAR 1,500 /kWh subsidy is introduced. The following figure shows the improvement in the NPV probability density. Summary statistics in Table 21 in **Error! Reference source not found.**.

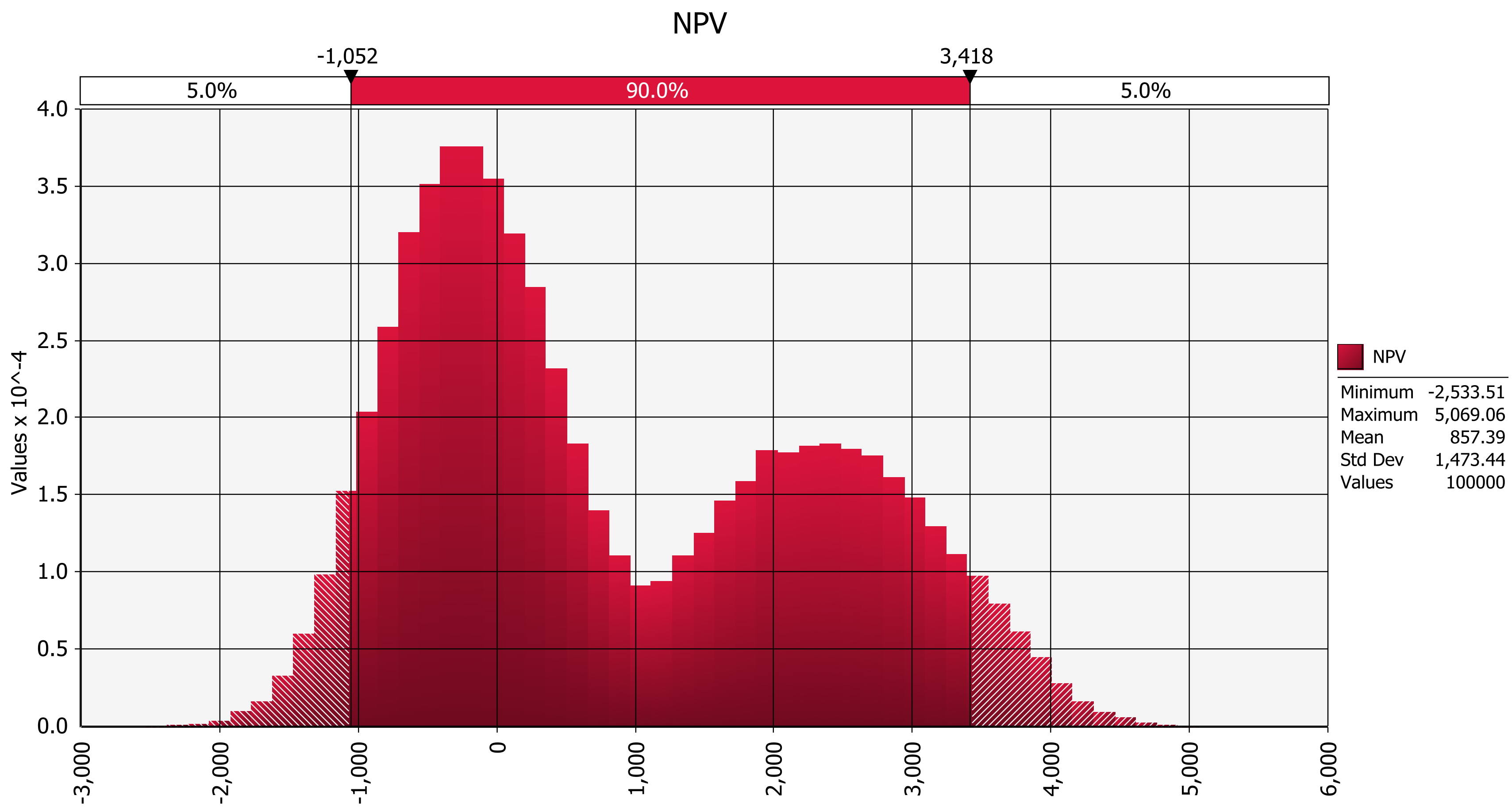

Figure 32.NPV probability density distribution, output result by the Monte Carlo simulation for 100,000 iterations (with the introduced subsidy of QAR 1,500/kWh)

As expected and discussed in the previous section, the introduced subsidy causes an increase in the NPV figures. This simulation provides more realistic ranges of NPV as it is applied for 100 thousand iterations and with wider range of assumed input variations, helping in the new proposed policy formulation in next section.

Section 7.3 Residential Solar PV Policy Formation

According to the data presented in Chapter 3 on the power consumption rates and power distribution per sector, the proposed policy is targeting the domestic sector (hence commercial and residential consumers) as the majority of power is consumed by this sector. Moreover, the targeted population is the consumers with tariff rate QAR 0.1/KWh and above as the NPV resulted for this range is -QAR 259.97 and higher, as shown in the first section of this Chapter.

Assuming an 80% system efficiency, a 1kWh system with a QAR 1500 subsidy would generate 800 Wh. The below table shows the subsidy amount for different system sizes assuming the targeted population of maximum 10,000 consumer to help in defining the maximum system size covered in the proposed policy:

Table 5. Different installed system sizes (kWh) with their corresponding Actual power generation (Watt/hour) and total subsidy amount for 10,000 supported customers

Installed system size (kWh)	Actual power generated (Wh)	Subsidy amount (QAR/Installed system)	Total power generated (MWh)	Power offset from peak demand of 6000 MW	Total subsidy amount in million (M) for 10,000 consumers
1	800	QAR 1,500	8	0%	QAR 15
5	4,000	QAR 7,500	40	1%	QAR 75
10	8,000	QAR 15,000	80	1%	QAR 150
15	12,000	QAR 22,500	120	2%	QAR 225
20	16,000	QAR 30,000	160	3%	QAR 300
25	20,000	QAR 37,500	200	3%	QAR 375
30	24,000	QAR 45,000	240	4%	QAR 450
35	28,000	QAR 52,500	280	5%	QAR 525
40	32,000	QAR 60,000	320	5%	QAR 600
45	36,000	QAR 67,500	360	6%	QAR 675
50	40,000	QAR 75,000	400	7%	QAR 750

As shown in the table, the total power generated by the different system sizes and assumed population of 10,000 consumer is not exceeding 7% of the peak demand in the summer (6000 MW in 2014).However, due to the very high amounts of required subsidy the installed system size in the proposed policy is not more than 10kW, this helps in motivating the renewable energy systems deployment in the country.

According to the information provided, the proposed policy suggests the government to offer an incentive amount of QAR 1.5/Watt installed of residential solar PV system to the consumers for a system size range between 1kW and 10kW maximum. The next table summarizes the proposed policy.

Section 7.4 Proposed Residential Sola PV Support Policy

Table 6. Residential sola PV support policy details and conditions

Policy Creation Date	November-2016
Implementing Sector	Residential and commercial
Incentive Type	Incentive to install
Eligible Technology	Solar Photovoltaic
Effective Date	January-2017
Incentive Amount	QAR 1.5/Watt
Maximum Incentive Amount	QAR 15,000/ System
Minimum System Size	1 kW
Maximum System Size	10 kW
Maximum Supported Consumers	10,000 Consumer

Policy Conditions:

- The size of eligible individual systems must not exceed 10kW
- The installed system size should not produce an excess power of more than 30% of the annual power consumption to be eligible for the incentive.
- Customers may apply for the incentive before the installation of the system only.
- No retroactive reimbursement granted.
- Customers can apply for only one reimbursement for every point of service.
- The system must be new and complying to the regions utility requirements.
- The system performance must comply to the minimum estimated performance of 80% of optimum system performance.
- All system components must meet Ashghal - Public Works Authority - standard quality and safety requirements.
- All installation must be approved by Kahramaa.
- The system installation may be subjected to multiple inspections and performance monitoring by Kahramaa throughout the system lifetime.
- Kahramaa has the right to disconnect the system for any incompliance reasons.

Section 7.5 Estimated Environmental Impact

It is worth to mention that all calculations to this point are not considering the environmental advantage of the system. Hence the CO_2 emissions elimination and the corresponding environmental savings in monetary value. As mentioned in (Chamoun & Charkroun, 2014) and other reviewed papers, the estimated dollar value for CO_2 emissions is approximately $30/ton which corresponds to $0.33/kg of CO_2 emissions. Where approximately 0.718kg of CO_2 is produced for every 1 kWh generated by the conventional electricity generation plant fueled by natural gas.

The below table summarizes the related assumptions and CO_2 savings of the 1 kW PV system, detailed calculations in the appendix.

Table 7. Solar PV environmental impact, data assumptions and calculations results

CO2 emissions in Kg/kWh	0.718
CO2 savings in $/ton	30
CO2 savings in $/Kg	0.033
CO2 savings in QAR/Kg	0.120
CO2 yearly savings by 1kW Solar PV system in kg/year (100% efficiency)	1866.8
CO2 yearly financial savings by 1kW Solar PV system in QAR/year (100% efficiency)	224.71
CO2 yearly emissions savings for first 10 years of the system lifetime in kg/year (90% efficiency)	1680.12
CO2 yearly emissions savings for year 11 to year 25 of the system lifetime kg/year (80% efficiency)	1493.44
Total CO2 emissions savings through the system useful life (25 years) in kg	39202.80
Total CO2 emissions savings through the system useful life (25 years) in QAR	4718.93

Thus, it is valuable to estimate the systems NPV considering the estimated financial value of environmental impact. This estimation combines the economic and environmental value of the system that is overlooked by most customers. The following figure shows the NPV resulted by considering the CO2 savings for different tariff rates and system installation costs. As expected, the NPV value improved when considering the estimated monetary value of environmental impact.

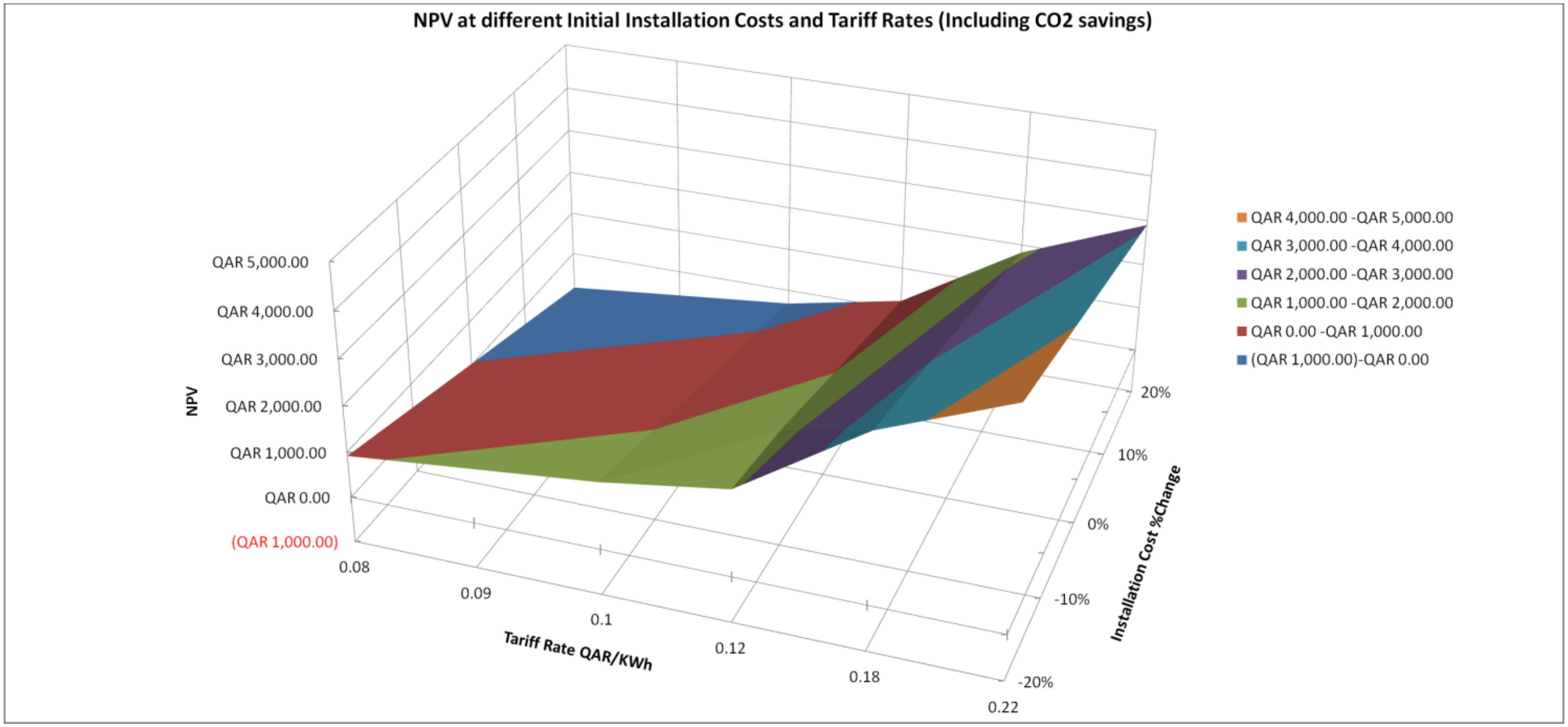

Figure 33. Surface diagram for NPV resulted for different solar PV system installation costs and tariff rates, including the financial value of CO2 savings

The next graph compares the NPV of the two approaches where CO_2 emissions is included vs. excluded from the calculations. Showing that the systems value is more environmental than economical, as NPV in case of evaluating the CO_2 emissions is always positive unlike the case of excluding the environmental value. The calculations are applied on the \$1055 system cost for different tariff rates as shown in the figure.

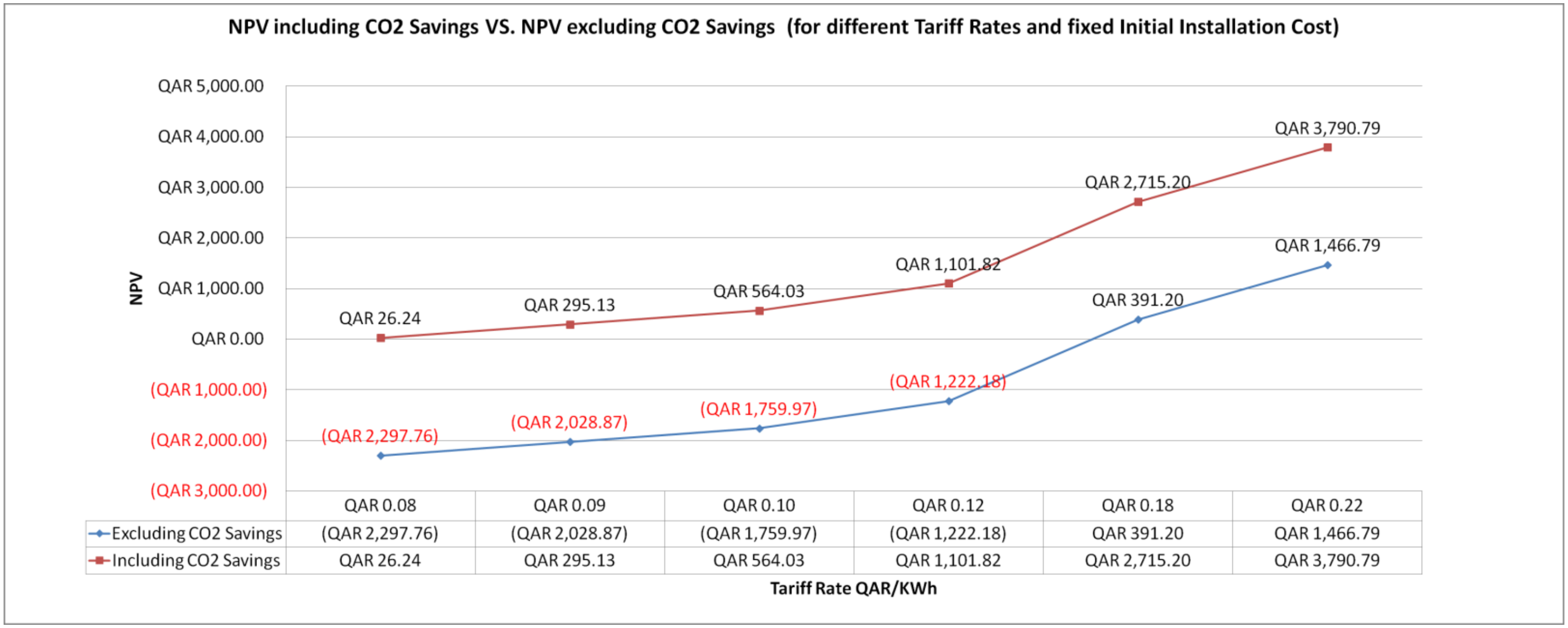

Figure 34. Comparing NPV including CO2 savings vs. NPV without considering the CO2 savings by 1kW Solar PV system with differetn tariff arates and fixed installation and O&M cost

CHAPTER 8. COCLUSION AND RECOMMENDATIONS FOR FUTURE STUDIES

The difficulties in changing Qatar’s over dependence on hydrocarbons are a mix of low prices of fossil fuel power generation and the point that Renewable Energy Sources (RES) technologies are not experienced yet locally. Thus, a pioneering attitude and political efforts are needed to support RE technologies in the country. Water and electricity tariffs have been heavily subsidized for decades by KAHRAMAA. As a result, renewable energy technologies became more expensive to deploy, and not the first option as an investment compared to the gas-fired water and electricity generation projects.

The government should be motivated by the requirements and economic efficiency, and instead of purchasing electricity and water generated by fossil fuels from IPWPs through KAHRAMAA, and find more ways to decrease the cost of gas consumed in producing commodities and make tariffs reflect these costs, on one hand, and seek energy generated by clean sources on the other hand. Consequently, this will help the country to mitigate the country’s environmental risks, and boost end-use energy efficiency.

One way of making solar PV attractive for local deployment is by introducing an incentive plan that provides an incentive of QAR1.5/Watt for installed Solar PV capacity. Initially the policy supports system size range between 1kW to 10kW.This introduced subsidy makes the solar pv system economically attractive for consumers with 6000kWh consumption rate and beyond as it has mean NPV of approximately QAR800.

This proposed policy requires an investment of QAR150 million in solar PV deployment. However, this large investment would significantly facilitate the deployment of solar energy locally, opening the doors for residential and commercial consumers to invest in this area .This offers huge advantage for the country in other areas such as mitigating the environmental risks and decreasing the domestic dependence on hydrocarbons.

Like any system, the solar PV system has some limitations. The following points summarize the main limitations associated with the solar PV system and some were considered during the policy formulation and system calculations:

- Solar panels operate only during the day and clear weather. PV panels do not operate during the night or during cloudy or rainy weather.
- Al system components mentioned above are required for the solar PV system to convert direct electricity (DC) to alternating electricity (AC).
- For on-grid connections, storage batteries are required for continuous supply.
- In case of land-mounted PV panel installations, they require relatively large areas for deployment; usually the land space is committed for this purpose for a period of 15-20 years – or even longer.
- Solar panels efficiency levels are varying from one system to another and degrades through time. However this variation was considered during the calculations.
- Although PV panels have no significant operations and maintenance costs, the panels are fragile and can be damaged relatively easily. Hence, additional

insurance costs essential to safeguard a PV investment. This was absorbed in the O&M cost variation in the sensitivity analysis.

The RE market can be more focused on, developed, or significant, if it has been introduced to tax credits, feed in tariffs or other policies that had shown success when deployed in certain markets. The (PPP) public private partnership have become the model for acquiring new power and water desalination capacity in Qatar. The country can offer such extended established model structure within which RES utilization projects can flourish

Also, it is worth to mention that the system becomes more lucrative as the government withdraws the subsidies. This policy change will impact the centricity tariffs directly, hence increase, would significantly increase the economic value of the solar PV system. As emphasized in the sensitivity analysis section, tariff rate is has the highest impact on the NPV.

Additionally, beside the financial and economic aspects of the solar PV deployment, the government should be motivated to invest in solar PV deployment for its high environmental advantage. This advantage can be evaluated financially improving the system's NPV. Although this value is only qualitative, yet it is important for improving the ecological situation of the country.

In future, further analysis could be done in evaluating the solar PV system economically, considering the decreasing prices trend of PV panels and the local PV technologies, as well as the hydrocarbons domestic consumption reduction and GDP growth resulted by the solar system deployment. Also further studies could investigate the value of integrating solar PV system with hybrid solutions and batteries backups.

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APPENDIX A: KAHRAMAA DATA STATISTICS OF POWER GENERATION AND CONSUMPTION

Table 8. Key electricity demand and supply growth indicators (from 2010 to 2014)

Growth Indicators	2010	2011	2012	2013	2014	% Average
Generated, GWh	28,144	30,730	34,788	34,668	38,693	10.0%
% Change	16.5%	9.2%	13.2%	-0.3%	11.6%	
Sent out, GWh	26,385	28,383	32,352	32,225	36,125	10.4%
% Change	18.5%	7.6%	14.0%	-0.4%	12.1%	
Maximum Demand MW	5,090	5,375	6,255	6,000	6,740	8.5%
% Change	12.2%	5.6%	16.4%	-4.1%	12.3%	
Number of electricity costumers (based of number of meters)	252,893	272,745	288,903	293,604	310,107	5.8%
% Change	7.8%	7.8%	5.9%	1.6%	5.6%	

Table 9.Electricity contracted capacity by Independent Power & Water Producers (IPPS) in 2014. Source **(KAHRAMAA Statistics Report, 2014)**

Independent Power & Water Producer	Contracted Capacity, MW
Qatar Electricity & Water company	
Ras Abu Fontas -A	497
Al Sailiyah (Satellites)	122
Doha Super South (Satellites)	61
Ras Abu Fontas B	609
Ras Abu Fontas B1	423
Ras Abu Fontas B2	567
Ras Avu Fotas Sub -Total	2,279
Ras laffan	
Ras laffan A(Ras laffan Power company)	756
Ras Laffan B (Q Power)	1,025
Ras Laffan C (Ras Girtas Power Company)	2,730
Ras Laffa Sub-Total	**4,511**
Mesaieed Power Company Limited	
Mesaieed Power station	2,001
Total Capacity	**8,791**

Table 10.Monthly gas consumption by Independent Power & Water Producers (IPPS) for power generation in 2014.Source **(KAHRAMAA Statistics Report, 2014)**

	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Total**
RAFASAT	5,682,056	5,276,676	6,340,836	7,465,714	8,880,226	7,607,937	8,849,508	8,870,524	8,212,042	9,248,339	7,134,995	5,589,720	**89,158,573**
RAF B	3,346,785	3,208,095	3,690,920	3,559,968	3,809,179	4,523,150	4,767,030	4,582,125	3,776,327	3,794,822	3,539,737	3,630,541	**46,228,679**
RAF B1	1,589,554	1,556,300	2,568,829	2,816,495	2,769,854	2,794,042	2,899,995	2,896,749	2,698,285	2,171,318	1,993,531	1,987,325	**28,742,276**
RAB B2	3,029,165	2,488,727	2,915,671	2,849,782	3,065,849	2,964,698	3,111,708	3,723,564	3,042,634	3,274,453	3,139,629	3,042,458	**36,648,334**
RLA	3,304,339	2,499,220	2,860,011	3,539,748	4,370,137	4,343,069	4,724,551	4,252,019	4,756,342	4,802,797	3,164,998	3,328,604	**45,945,835**
RLB	3,750,394	3,498,704	4,023,342	3,869,139	5,353,301	5,614,570	6,109,101	6,055,889	5,608,343	5,351,601	4,105,932	4,172,931	**57,513,245**
MPCL	1,474,760	1,802,365	2,624,987	3,665,362	4,772,533	5,741,127	5,908,943	6,031,901	5,826,383	5,616,443	3,938,427	2,204,746	**49,607,976**
RGPC	4,412,124	4,018,310	4,996,975	5,981,427	7,485,190	7,588,955	8,905,726	9,096,143	9,014,213	7,328,911	5,968,488	4,909,931	**79,706,436**
Total	**26,589,176**	**24,348,397**	**30,021,571**	**33,747,679**	**40,506,269**	**41,177,548**	**45,276,561**	**45,508,913**	**42,934,569**	**41,588,683**	**32,985,733**	**28,866,254**	**433,551,354**

Table 11.Monthly electricity generation by different power generation plants in 2014.Source **(KAHRAMAA Statistics Report, 2014)**

Month	RAF B	RAF B1	RAF B2	RAFA	Satellites	RLPC	RLB	MPCL	RGPC	Total
Jan.	343,555	132,140	223,776	161,567	34,960	310,359	282,071	166,561	401,871	**2,056,860**
Feb.	331,185	129,370	182,126	145,193	63,350	229,363	254,302	190,023	357,945	**1,882,857**
Mar.	369,013	220,115	220,062	169,985	80,720	221,963	296,794	364,379	468,526	**2,411,556**
Apr.	358,802	244,297	216,730	244,734	103,170	331,881	288,079	506,513	607,072	**2,901,278**
May	382,345	241,471	231,702	288,302	131,530	424,134	512,571	666,061	807,638	**3,685,754**
Jun.	449,755	242,160	224,645	249,659	102,300	415,400	611,359	806,040	827,033	**3,928,351**
July	468,092	251,105	240,020	284,084	131,450	504,203	674,959	836,877	1,028,741	**4,419,531**
Aug.	447,755	251,049	289,703	286,800	133,030	440,912	673,570	851,107	1,057,454	**4,431,380**
Sept.	364,980	232,167	237,449	272,758	118,330	503,307	586,057	819,128	1,045,039	**4,179,215**
Oct.	373,616	187,967	253,589	294,349	99,270	507,936	491,862	772,738	801,736	**3,783,063**
Nov.	358,851	171,848	236,344	253,270	26,660	258,482	282,090	548,365	589,493	**2,725,403**
Dec.	367,263	173,378	223,029	195,929	-	289,289	283,413	300,472	454,860	**2,287,633**
Total	**4,615,212**	**2,477,067**	**2,779,175**	**2,846,630**	**1,024,770**	**4,437,229**	**5,237,126**	**6,828,264**	**8,447,408**	**38,693,880**

APPENDIX B: ELECTRICITY TARIFFS IN QATAR

Table 12.Electricity tariffs for residential consumers in Qatar. Source **(Electricity Tariffs Rate, 2016)**

From (kWh)	To (kWh)	Electricity Tariff (QAR/kWh)
1	2,000	0.08
2,001	4,000	0.09
4,001	6,000	0.1
6,001	8,000	0.12
8,001	15,000	0.18
15,001	Maximum	0.22

APPENDIX C: SOLAR PV SYSTEM PRICE QUOTATION AND SPECIFICATIONS

The below link is for a quotation obtained from Alibaba.com website for 2 kW solar power grid system with grid tie inverter and solar kit. System with 250 Watt panels. Free shipping and total item price $ 2,200 including installation costs.

Total cost = $2110 = QAR 7680.4

Cost per 1kW = $1055 = QAR 3840.2

https://solarleading.en.alibaba.com/product/1991063484-222447359/2kw_solar_power_grid_systems_2kw_with_grid_tie_inverter_and_solar_kit.html

Quick Specifications:

Table 13.Quick PV system specifications

Place of Origin:	China (Mainland)
Specification:	Normal
Load Power (W):	2000w
Nominal AC Voltage:	220V-240V
Grid Tied Solar Inverter:	2000TL
AC Breaker:	Air Breaker 440V
MC4 Connectors:	SLMC4
Brand Name:	Solar Leading
Application:	Home
Solar Power (W):	2000w
Nominal AC Frequency:	50Hz/60Hz
Mounting Brackets:	Optional
Monitor:	Wi-Fi Plug
Model Number:	SLGT-2.00KW
Output Voltage (V):	220V-240V
Work Time (h):	8hrs
Solar PV Modules:	8pcs SL6P60-250Watt
DC Isolator:	DC600V
PV Connection Cables:	4/6 S.q.mm

Complete Package

Table 14.Complete PV system package details.

SLGT-2.00KW - Single Phase				
Nominal Power of PV Generator (W)		2000Watt		
Nominal AC Voltage		220V-240V		
Nominal AC Frequency		50Hz/60Hz		
	Item	**Model No.**		**Quantity**
1	Solar PV Modules	250W Poly Crystalline	SL6P60-250Watt	8
2	Grid Tied Solar Inverter	JSI-2000TL		1
3	Mounting Brackets	Tile roof	JX-1001	1
4	DC Isolator	Water Proof IP67	DC600V	1
5	AC Breaker	Water Proof IP65	Air Breaker 440V	1
6	Monitor	Wi-Fi Plug		1
7	Ground Earth Cable	6 S.q.mm		20
8	PV Ground Earth Clamp	Copper with screws		16
9	DC PV Connection Cables	4/6 S.q.mm		20
10	MC4 Connectors	SLMC4		3

Advantages

- On grid solar system will reduce the power bill as it is possible to sell surplus electricity produced to the local electricity supplier.
- On grid solar system are comparatively easier to install as they do not require a battery system.
- On grid solar system has the advantage of effective utilization of generated power because there are no storage losses involved.
- On grid solar system is carbon negative over its lifespan, as any energy produced over and above that to build the panel initially offsets the need for burning fossil fuels. Even though the sun doesn't always shine, any installation gives a reasonably predictable average reduction in carbon Consumption.
- Designed for low-light and highly exposed locations
- Quick and low cost to deploy
- Rated from -35 to 85°C (operational)
- Industrial electrical infrastructure designed for seamless integration with existing systems
- NEC code compliant over current, lightning protection and safety disconnect
- Solid-state electronics
- TUV/IEC/CE listed components
- Designed for environmentally challenged locations

- 25 years lifetime warranty, 10years quality warranty for solar modules and 10years warranty for full system.

APPENDIX D: SOLAR PV SYSTEM COST AND ECONOMICAL CALCULATIONS

In the following, detailed calculations steps for the Solar PV system cost and economic data analyzed in CHAPTER 7. The calculations based on reviews provided by (Calculating the Kilowatt Hours Your Solar Panels Produce (Solar Panel Output), 2016), (W.D. Kellogg, 1998), (Chamoun & Charkroun, 2014), (Ren, Gao, & Ruan, 2009), and (Richter, 2009)

Data Assumptions based on the reviews of literature:

- Average Solar insulation in Qatar = 2140 kW/m^2 / year
- Average Solar daily peak hours in Doha = 8 hours/day
- Average annual operating days = 325 Days/ year (minimum days of operation, considering the weather conditions and assuming that the weather and system conditions are suitable for operation during this specified period)
- Discount Rate estimated to be 6%
- Inflation Rate is assumed to be zero
- System useful life = 25 years based on the system specifications provided earlier
- Cost for Solar PV installation estimated to be $1055 = QAR 3840.2 based on the 2kW system cost mentioned earlier.
- Operations and Maintenance cost (O&M) estimated to be 1% of the initial installation cost. This number is assumed based on the reviews and selected system specifications, where the number range was from 1% to 6% in the

reviews, and selected PV system has a warranty for 25 years as mentioned in specifications. So the minimum percentage was selected to cover cost variation.

- Module efficiency 25% and system efficiency 90% for first 10 years and 80% for the remaining years of the system useful life.
- Maximum module output power (100% efficiency) = 1kWh

Step 1: Calculate the annual O&M cost:

O&M cost = 0.01 x Installation Cost = 0.01 x $1055 = $10.55

O&M cost in QAR = $10.55 x 3.64 = QAR 38.40 annually

Step2: Calculate system annual operating hours:

Annual operating hours = Average annual operating days x Average Solar daily peak hours

Annual operating hours = 325 days/year x 8 hours/day = 2600 hours/ year

Step 3: Calculate the system annual savings/revenues:

For 100%efficiency, zero subsidy and tariff rate of QAR 0.09/kWh,

Total Annual savings = (Annual operating hours x System maximum output in kWh x Tariff Rate) - O&M annual cost

Total Annual savings = (2600 hours/year x 1kWh x QAR 0.09 /kWh) - QAR 38.40 = QAR 195.60

For the first year and 90% efficiency, Annual savings = 0.9 x QAR 195.60 = QAR 176.04

For year 2 to year 10 and 90% efficiency, Annual savings = (0.9 x QAR 195.60) - QAR 38.40 = QAR 137.64

For year 11 to year 25 years and 80% efficiency, Annual savings = (0.8 x QAR 195.60) - QAR 38.40 = QAR 118.08

Step4: Calculate the System Total Annual Savings

System Total Annual Savings = Savings for the first year + savings for year 2 to year 10 + savings for year 11 to year 25

System Total Annual Savings = (QAR 176.04 x 1 year) + (QAR 137.64 x 9 years) + (QAR 118.08 x 15 years)

System Total Annual Savings = QAR 3,185.95, hence without considering the initial cost and discount rate yet

Step4: Calculate the System NPV

Using excel NPV formula and the calculated data of Initial installation cost and system annual savings in previous steps , with discount rate of 6% and system useful life of 25 years and zero subsidy.

NPV (Discount Rate, Installation Cost, Subsidy, Total annual savings for 25 years) = - QAR 2,028.87

The same steps were used to calculate all NPV in Chapter 6.

APPENDIX E: NPV AT DIFFERENT INITIAL INSTALLATION COSTS AND TARIFF RATES

Table 15.NPV at different initial installation costs and tariff rates

Installation Cost (QAR/kWh)	Tariff Rate in QAR					
	0.08	0.09	0.10	0.12	0.18	0.22
	NPV in QAR					
3072.16	(1,407.98)	(1,139.08)	(870.18)	(461.07)	1,280.99	2,356.57
3456.18	(1,852.87)	(1,583.97)	(1,315.08)	(777.28)	836.09	1,911.68
3840.2	(2,297.76)	(2,028.87)	(1,759.97)	(1,222.18)	391.20	1,466.79
4224.22	(2,742.65)	(2,473.76)	(2,204.86)	(1,667.07)	(53.69)	1,021.89
4608.24	(3,187.55)	(2,918.65)	(2,649.76)	(2,111.96)	(498.59)	577.00

APPENDIX F: NPV AT DIFFERENT TARIFF RATES AND DIFFERENT SUBSIDY

Table 16. NPV at different tariff rates and different subsidy

Subsidy		Installation Cost	Tariff Rate in QAR					
QAR/kWh	$/W	QAR/kWh	0.08	0.09	0.10	0.12	0.18	0.22
			NPV in QAR					
0.00	0.00	3840.20	-2297.76	-2028.87	-1759.97	-1222.18	391.20	1466.79
1000.00	0.27	3840.20	-1297.76	-1028.87	-759.97	-222.18	1391.20	2466.79
1500.00	0.41	3840.20	-797.76	-528.87	-259.97	277.82	1891.20	2966.79
2000.00	0.55	3840.20	-297.76	-28.87	240.03	777.82	2391.20	3466.79
2500.00	0.69	3840.20	202.24	471.13	740.03	1277.82	2891.20	3966.79
3000.00	0.82	3840.20	702.24	971.13	1240.03	1777.82	3391.20	4466.79
3500.00	0.96	3840.20	1202.24	1471.13	1740.03	2277.82	3891.20	4966.79
4000.00	1.10	3840.20	1702.24	1971.13	2240.03	2777.82	4391.20	5466.79

APPENDIX G: SOLAR PV SYSTEM ENVIRONMENTAL VALUE CALCULATIONS

In order to include in the NPV calculation the financial value of CO2 emissions savings, need to calculate first the annual financial value of CO2 emissions savings. The following steps present the detailed calculations given that 0.718 kg/kWh of CO2 is produced by the conventional power generation plant, hence saved by the solar PV system. With a value of $30/ton financial. (Chamoun & Charkroun, 2014) (Energy Efficiency / CO2 Indicators for Qatar , 2014)

<u>Step1: Calculate amount of CO2 yearly savings by 1kW Solar PV system</u>

CO2 produced by 1kW power generation = 0.718 kg/kWh

CO2 saved by 1kW solar PV system annually = CO2 produced by 1kW power generation x Annual operating hours of solar PV system x power generated by solar PV system hourly

CO2 saved by 1kW solar PV system annually = 0.718 kg/kWh x 2600 hours/year x 1kW= 1866.8 kg/year

<u>Step2: Calculate CO2 yearly financial savings for 100% efficient system in QAR/year</u>

CO2 yearly financial savings by 100% efficient system = CO2 savings financial value in QAR/Kg x amount of CO2 saved by 1kW solar PV system annually

CO2 yearly financial savings by 100% efficient system = 0.120372361 QAR/kg x 1866.8 kg/year = QAR 224.7111229 / year

Step3: Calculate amount of CO_2 yearly savings for 90% efficient system in kg/year

Amount of CO_2 yearly savings by 90% efficient system = CO_2 saved by 1kW solar PV system annually x system efficiency

Amount of CO_2 yearly savings by 90% efficient system = 1866.8 kg/year x 90% = 1680.12kg/year

Step4: Calculate amount of CO_2 yearly savings for 80% efficient system in kg/year

Amount of CO_2 yearly savings by 80% efficient system = CO_2 saved by 1kW solar PV system annually x system efficiency

Amount of CO_2 yearly savings by 90% efficient system = 1866.8 kg/year x 80% = 1493.44kg/year

Step5: Calculate amount of CO_2 savings for the system useful life in kg

Total CO_2 emissions savings through the system useful life (25 years) = (Amount of CO_2 yearly savings by 90% efficient system x 10 years) + (Amount of CO_2 yearly savings by 80% efficient system x 15 years)

Total CO_2 emissions savings through the system useful life (25 years) = (1680.12kg/year x 10 years) + (1493.44kg/year x 15 years) = 39202.8 kg of CO_2

Step6: Calculate CO_2 financial savings for the system useful life in QAR

Total CO_2 emissions financial savings through the system useful life (25 years) = Total CO_2 emissions savings through the system useful life (25 years) x CO_2 savings financial value in QAR/kg

Total CO_2 emissions financial savings through the system useful life (25 years) = 39202.8 kg of CO_2 x 0.120372361 QAR/kg = QAR 4718.93358

For the NPV calculations, the annual CO_2 financial saving is inserted in step 3 equations of economical calculations

APPENDIX H: NPV INCLUDING CO2 SAVINGS VS. NPV EXCLUDING CO2 SAVINGS (FOR DIFFERENT TARIFF RATES AND FIXED INITIAL INSTALLATION COST)

Table 17.NPV including CO2 Savings VS. NPV excluding CO2 Savings (for different tariff rates and fixed initial installation cost)

Installation Cost			**Tariff Rate in QAR**					
Change	**QAR/kWh**	**$/kWh**	0.08	0.09	0.1	0.12	0.18	0.22
			NPV in QAR					
-20%	3072.16	844	916.02	1,184.92	1,453.82	1,862.93	3,604.99	4,680.57
-10%	3456.18	949.5	471.13	740.03	1,008.92	1,546.72	3,160.09	4,235.68
0%	3840.2	1055	26.24	295.13	564.03	1,101.82	2,715.20	3,790.79
10%	4224.22	1160.5	(418.66)	(149.76)	119.14	656.93	2,270.31	3,345.89
20%	4608.24	1266	(863.55)	(594.65)	(325.76)	212.04	1,825.41	2,901.00

APPENDIX I: SIMULATION DATA & STATISTICS SUMMARY

Table 18. Simulation model input summary

Name	Distribution type	Min	Mean	Max
Installation Cost	Normal Distribution	-∞	-$ 1,055.00	+∞
O&M%	Normal Distribution	-∞	1	+∞
Discount Rate	Discrete Uniform Distribution	5%	6%	7%
Tariff Rate	Discrete Uniform Distribution	QAR 0.08	QAR 0.14	QAR 0.22

Table 19. Simulation variables result summary

Input Variable Name	Min	Mean	Max	5%	95%
Installation Cost	-$ 1,508.88	-$ 1,055.00	-$ 573.41	-$ 1,228.54	-$ 881.47
O&M%	0.573477	1	1.444216	0.8355103	1.164483
Discount Rate	5%	6%	7%	5%	7%
Tariff Rate	QAR 0.08	QAR 0.14	QAR 0.22	QAR 0.08	QAR 0.22

Table 20. Summary statistics for NPV with zero subsidy

Statistics		Percentile	
Minimum	(QAR 4,139.48)	5%	(QAR 2,550.39)
Maximum	QAR 3,736.85	10%	(QAR 2,314.15)
Mean	(QAR 642.33)	15%	(QAR 2,136.39)
Std Dev	QAR 1,473.16	20%	(QAR 1,989.01)
Variance	2170203.694	25%	(QAR 1,850.13)
Skewness	0.435248186	30%	(QAR 1,716.53)
Kurtosis	2.000926391	35%	(QAR 1,579.78)
Median	QAR 0.00	40%	(QAR 1,439.90)
Mode	(QAR 1,811.30)	45%	(QAR 1,282.17)
Left X	(QAR 2,550.39)	50%	(QAR 1,093.04)
Left P	5%	55%	(QAR 846.79)
Right X	QAR 1,920.62	60%	(QAR 429.43)
Right P	95%	65%	QAR 41.40
Diff X	QAR 4,471.02	70%	QAR 368.76
Diff P	90%	75%	QAR 652.78
#Errors	0	80%	QAR 922.32
Filter Min	Off	85%	QAR 1,198.60
Filter Max	Off	90%	QAR 1,515.96
#Filtered	0	95%	QAR 1,920.62

Table 21. Summary Statistics for NPV with introduced QAR 1,500 subsidy

Statistics		**Percentile**	
Minimum	(QAR 2,533.51)	5%	(QAR 1,051.76)
Maximum	QAR 5,069.06	10%	(QAR 810.48)
Mean	QAR 857.39	15%	(QAR 636.45)
Std Dev	QAR 1,473.44	20%	(QAR 486.21)
Variance	2171033.769	25%	(QAR 348.92)
Skewness	0.436841864	30%	(QAR 216.26)
Kurtosis	1.996940645	35%	(QAR 82.92)
Median	QAR 398.98	40%	QAR 59.52
Mode	(QAR 176.39)	45%	QAR 216.27
Left X	(QAR 1,051.76)	50%	QAR 398.98
Left P	5%	55%	QAR 644.77
Right X	QAR 3,418.01	60%	QAR 1,070.72
Right P	95%	65%	QAR 1,539.69
Diff X	QAR 4,469.76	70%	QAR 1,872.08
Diff P	90%	75%	QAR 2,154.44
#Errors	0	80%	QAR 2,426.99
Filter Min	Off	85%	QAR 2,705.51
Filter Max	Off	90%	QAR 3,012.80
#Filtered	0	95%	QAR 3,418.01